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FREEZE - THAW CONDITIONING OF BIOTREATMENT PLANT SLUDGE

in

SUB-ARCTIC ALASKA

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By

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FREEZE - THAW CONDITIONING OF BIOTREATMENT PLANT SLUDGE

IN

SUB-ARCTIC ALASKA

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Larry Eugene Garinger, M.S.

ABSTRACT

The literature was searched for papers reporting research work done on freezing water, wastewater effluent, water treatment plant sludge and sewage treatment plant sludge. An experiment was conducted to determine the effect of freezing, provided naturally, as a conditioning step prior to the dewatering of sewage sludge. The sludge was drawn from a biological waste treatment plant located near Fairbanks in sub-Arctic Alaska. The analytical results and physical observations showed that freezing greatly enhanced the settling and dewatering characteristics of this sludge. A prototype design suggested the use of a pair of identical lagoons in which sludge would be poured to a maximum depth of 12 inches. Freezing would be effected during the winter months, thawing would occur in the spring and drying would be carried on during the summer and early fall. A peripheral cost estimate and simple logistics indicated that lagoons would compete very favorably with alternative methods of sludge dewatering.

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Notation

mg/l - Milligrams per liter

BOD - Biochemical Oxygen Demand

COD - Chemical Oxygen Demand

MLSS - Mixed Liquor Suspended Solids

SS - Suspended Solids

VSS - Volatile Suspended Solids

TS - Total Solids

TVS - Total Volatile Solids

WPCF - Water Pollution Control Federation

USPHS - United States Public Health Service

CHAPTER 1 INTRODUCTION

The technology pertaining to the removal of suspended and colloidal material from wastewater is well established. This solid material is usually removed by utilizing the physical process of settling in conjunction with flocculation. The flocculation can be achieved chemically or biologically. Removals of greater than 90 percent of the suspended material by means of conventional secondary treatment are considered routine. The separation of the solids from the wastewater yields two products in a sewage treatment plant; namely, the liquid effluent which is usually discharged to a watercourse and a slurry of solids, or sludge, which normally must be subjected to further treatment prior to ultimate disposal.

Since sludge production is associated with even the rudimentary forms of sewage treatment, the technology pertaining to its handling is also well established; nonetheless, not as much attention has been focused hereto as on overall treatment efficiency. Sludge conditioning, dewatering and ultimate disposal have been achieved using one, or a combination of, the following unit processes[1]:

Thickening
Blending
Anaerobic digestion
Elutriation
Lagooning-landfilling
Land Disposal of Liquid Sludge
Pipeline Transportation
Ocean Disposal-Dilution
Underground Disposal
Composting
Soil Conditioning
Incineration
Air Drying
Heat Drying
Vacuum Filtration

A totally satisfactory method of sludge treatment and disposal has not been developed for small sub-Arctic biological treatment plants although sludge production herefrom has been reported to be prolific.[2],[3] The conventional methods are often overly sophisticated, requiring skilled operation or are uneconomical for small sewage treatment plants. Several investigators[4],[5],[6],[7] have reported excellent improvements in water treatment plant sludge dewatering performance after the sludge had been subjected to freezing and thawing. The rejection of dissolved organic and inorganic material by freezing has been used as a method of water treatment.[8],[9],[10],[11],[12] The freezing of sewage sludge has been tried experimentally by several workers.[13],[14],[15],[16],[17] Two prototype installations[7],[18] are using natural refrigeration to freeze and condition water treatment plant sludge. All investigators have given positive indication that the freeze conditioning of sludge, both inorganic and organic, is feasible. However, when artificial means of freezing must be used, the economics of the freezing process are poor.[1],[19]

Sub-Arctic Alaska has an abundance of natural refrigeration. The mean annual temperature is 26°F and there are 160 days of the year when the maximum temperature is less than 32°F.[20] Sub-Arctic Alaska is experiencing increased population and there is evidence that sewage treatment facilities will continue to be installed and upgraded in more and more communities. Since the minimum acceptable sewage treatment generally allowable by state law is secondary treatment it is reasonable to forecast that ever increasing volumes of sludge will be produced. With these problems in mind, this project was designed to try to solve the sludge disposal problem in a simple and economical fashion, utilizing the natural refrigeration available.

Nine model sludge drying beds were constructed and placed near the oxidation ditch owned by College Utilities Corporation. This treatment facility, illustrated in Figure 1, receives and treats approximately 300,000 gallons of domestic sewage on an average day. Figure 2 shows a flow diagram of this biological waste treatment plant. The layout of the model sludge drying beds is shown in Figure 3. Sludge from the settling tank of the biological sewage treatment plant was poured into the model beds during three separate runs during the late winter of 1971. Variables included air temperature, sludge thickness, sludge depth and bed insulation.

The broad objectives of the research project were as follows:

1. To determine the optimum sludge depth and thickness for freezing and dewatering.

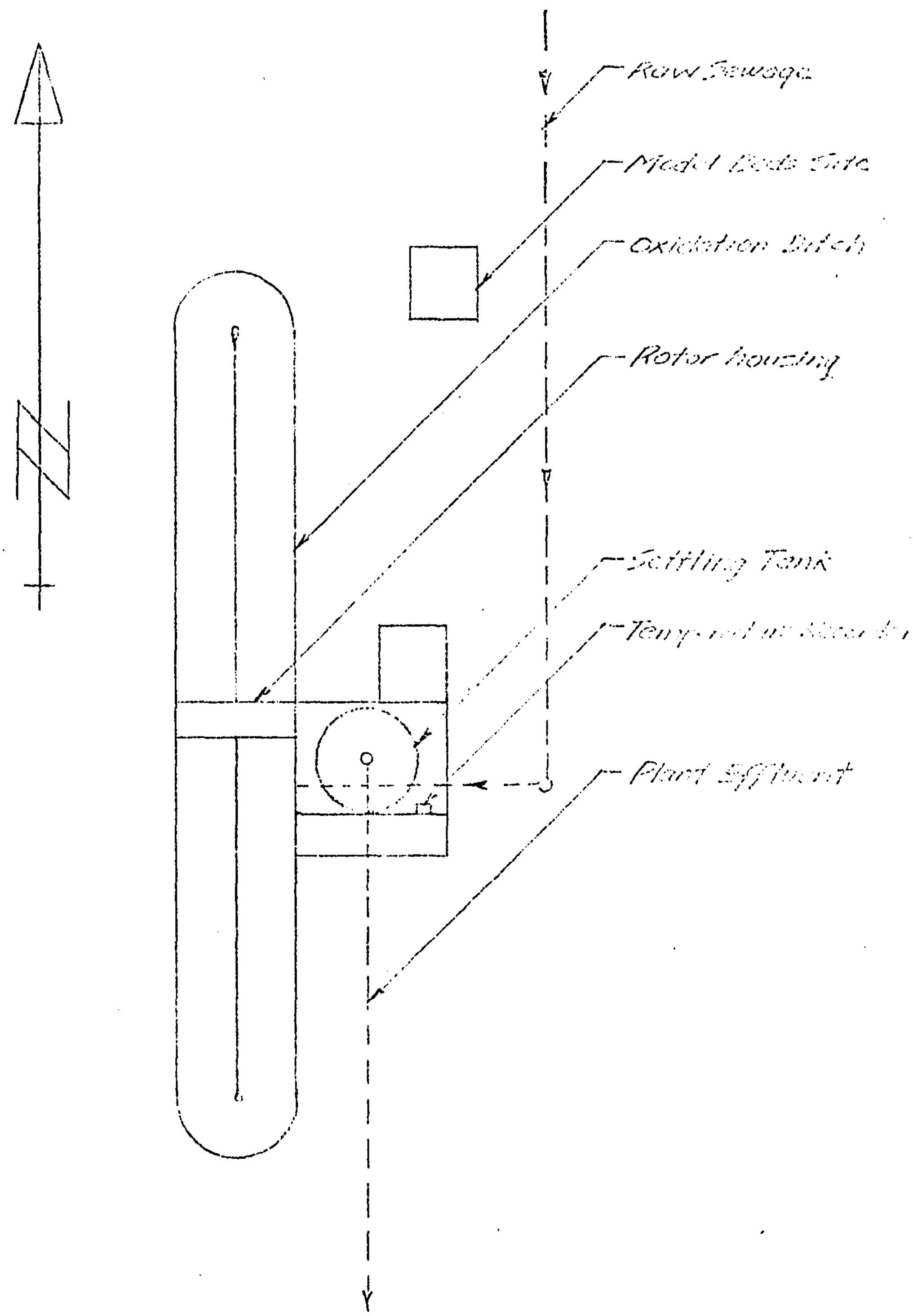
2. To closely observe the chemical and physical behaviour of the sludge during freezing, in the frozen state and during the thaw and drying.

3. To search the literature for all material published regarding freeze-thaw installations used for sludge conditioning.

4. To search the literature for alternative methods of sludge treatment and disposal for small sub-Arctic biological waste treatment plants.

5. To formulate a design for a prototype sludge freeze-thaw installation suitable for use in small sub-Arctic biological waste treatment plants.

Figure No. 1 Site Layout



Scale: 1" = 60'

Figure No.2 Flow Diagram for Existing Process

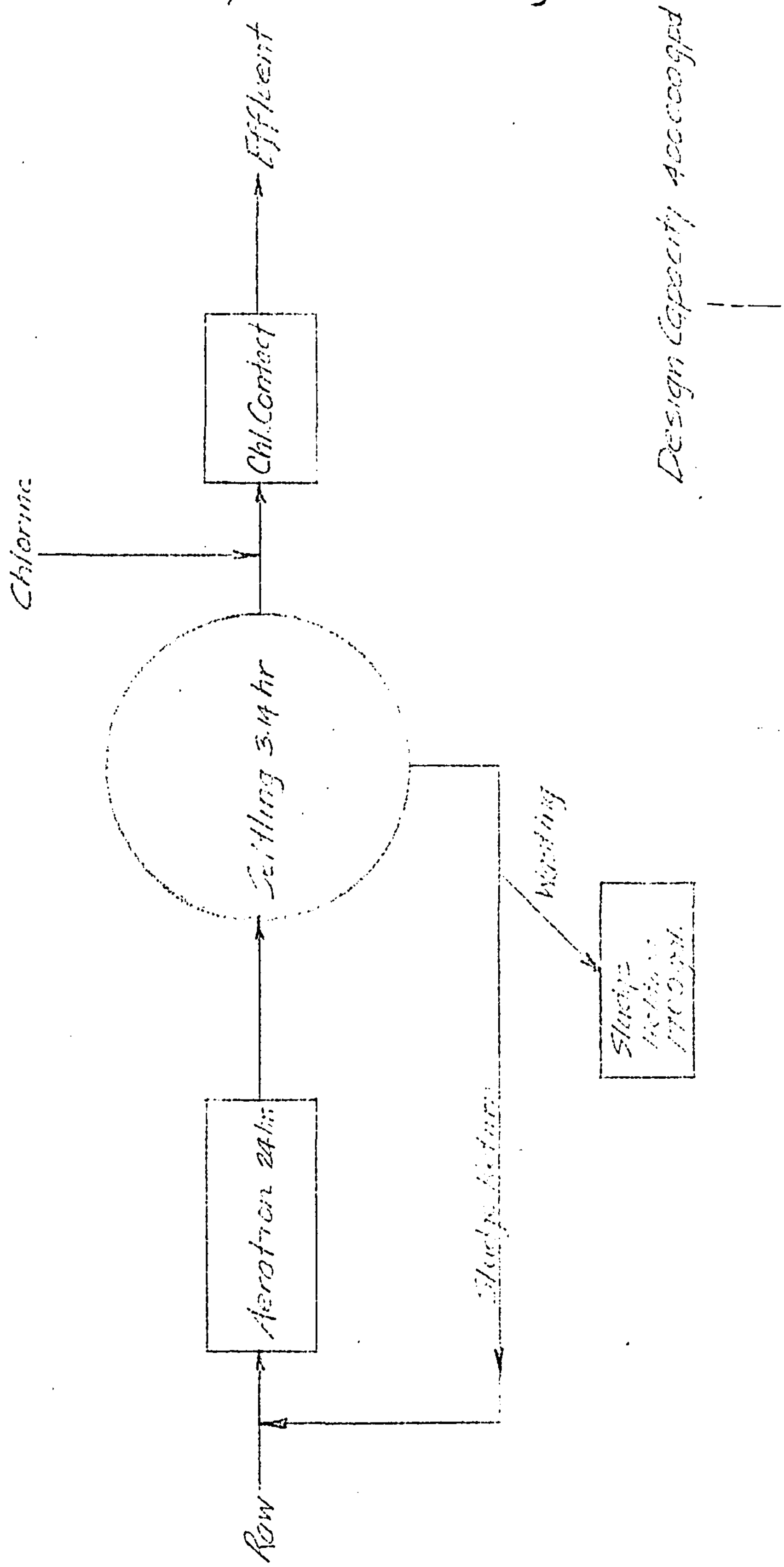
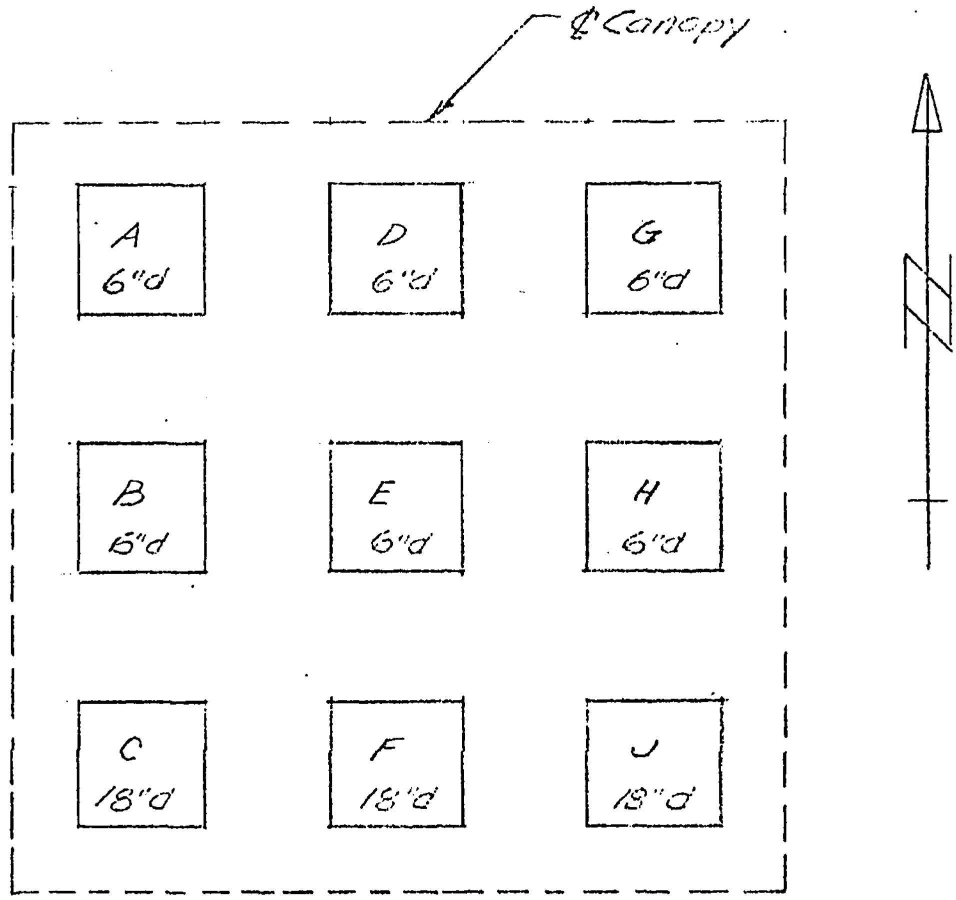


Figure No. 3 Schematic Layout of Model Beds



Scale: 1" = 60'

'd' denotes depth

CHAPTER II THEORETICAL CONSIDERATIONS; LITERATURE REVIEW

There is little argument in the literature as to whether freezing is effective in conditioning sludge prior to dewatering. Remarkable improvements in dewatering rates have been exhibited for both water treatment sludge, which is primarily inorganic in nature and sewage sludge, which is primarily organic. However, the mechanism of enhanced dewatering after a freeze-thaw cycle is not unanimously agreed upon. Some authors take only a fleeting look at the mechanism and accept it lightly while others delve into the theory more deeply. A significant portion of the literature pertains to a distinct facet of freeze-thaw treatment, that is, the purification of water using this mechanism. It is important to note the fundamental distinction between freeze-thaw treatment of sewage sludge as opposed to treatment of water. The freeze-thaw process is applied to sludge so that it will dewater more readily, thus reducing the volume of solids to be handled further. The freeze-thaw process has been applied to water to concentrate dissolved impurities in a liquid fraction. This is effected as pure ice crystals grow. It is the purpose of this chapter to delve into the literature published regarding freeze-thaw processes as applied to the field of sanitary engineering. Chapter VII will incorporate a literature survey of alternative means of sludge treatment and disposal.

A. Water Purification by Freeze-Thaw

Although it is not the focal point of this chapter, a brief study of the mechanism of water purification by freeze-thaw will facilitate understanding of the mechanisms involved in the freezing of sludge.

The freezing and gas hydrate processes for demineralizing sea water were adapted in a preliminary design to renovate municipal waste waters in a project supervised by USPHS.[8] Continuous reuse of water necessitates the removal of dissolved solids since a single use by a municipality adds approximately 300 mg/l total dissolved solids. The freezing, hydrate process is designed to remove pure water from its aqueous solution. To achieve good results, practically all suspended matter must be removed before freezing. Subsequent to freezing a small number of large crystals are washed. It was found that COD could be reduced by a factor of 3-7 and chlorides by a factor of 7-10 by this process. The process essentially involves partial freezing and draining followed by washing and melting the ice crystals. The majority of the impurities are concentrated in the mother liquor; therefore, purification depends on how much of the mother liquor can be removed. The process has a high cost but waste water renovation by this method was found to be more economical than saline water conversion by conventional methods.

A follow-up report by FWPCA[9] also discusses the removal of inorganic material from effluents by the freezing method. The process is similar to that discussed above - the feed water is cooled and slowly frozen; the ice is separated from the unfrozen brine, washed with clean water and melted to produce purified water. Although the process is considered to be one of demineralization,,it is also capable of removing organic materials from water. However, washing the organics from the ice crystals proved to be difficult in a pilot plant operation. It was found that freezing could not compete economically with carbon adsorption and electrodialysis. Carbon adsorption and electrodialysis were reported to cost 25-35 cents per thousand gallons while the freezing process cost 48 cents per thousand gallons of wastewater treated. Demineralizing sea water by the freezing process was reported to cost 53 cents per thousand gallons.

A Summary Report by the USPHS[10] stated that 85 percent of organic contaminants and 90 percent of inorganic contaminants can be removed from wastewater effluent by the freezing process.

A study conducted by R.A. Baker[12] used partial freezing of aqueous-organic solutions to achieve removal of trace organic contaminants. Single stage and double stage concentration, using acetophenone, volatile fatty acids and phenols as contaminants, were effected. Baker experienced difficulty measuring trace organic substances not readily measured by the most sensitive of presently available analytical devices.

Applied Science Laboratories conducted a study[11] pertaining to purification of mine water by freezing. By partial freezing, to the extent of about 50 percent conversion to ice, they managed a reduction of various metal and acid components in the product water of 85 to 90 percent, generally. It was also found in this study that suspended solids or colloidal particles must be removed before partial freezing because they are likely to contaminate the ice by being trapped within it. When a pure ice crystal forms from a solution, the impurities that were dissolved in the water, which formed the ice crystal, are left behind in the solution surrounding the ice crystal. Consequently, each ice crystal just after the moment of its formation is surrounded by a solution that is more concentrated than the original solution. The next ice crystal is thus more likely to be contaminated than the previously formed ice. In general, all dissolved metal salt impurities remain in the mother liquor when any kind of water is partially frozen but organic impurities vary in their behaviour, as do acids. The authors[11] report that a low rate of freezing would be expected to favor a high percentage reduction of impurities in natural ice if outdoor freezing were utilized. The authors were noncommittal in forecasting whether the method would be feasible for removal of organic material from sewage or wastewater solutions.

Wagner[21] carried out a series of experiments to evaluate the feasibility of using the freezing process as a method of concentration and treatment of raw domestic sewage. The results of single-stage batch freezing indicated that, although it was possible to concentrate the waste, the recovery efficiencies were not high enough to warrant further study at that time (1969).

B. Water Treatment Plant Sludge Dewatering

Complete water treatment plants, utilizing the unit processes of coagulation, sedimentation and filtration, often produce large amounts of sludge and wastewater. The sludge emanates from the sedimentation tanks where coagulated material, with enmeshed suspended solids and turbidity from the raw water, settle out. The nature of the sludge will depend upon the composition of the raw water, the treatment process used, and the type of coagulant used. Very frequently the coagulant is aluminum sulfate [$Al_2(SO_4)_3$] or alum. In this case a large part of the sludge will be gelatinous aluminum hydroxide [$Al(OH)_3$] with the entrapped turbidity and suspended solids. If the water treatment plant is removing hardness by chemical precipitation with lime and soda ash the sludge would be chiefly calcium carbonate [$CaCO_3$] and magnesium hydroxide [$Mg(OH)_2$]. In brief, the sludge produced by a complete water treatment plant is largely inorganic, which is usually in the form of a salt or a hydroxide. Wastewater and some sludge will result from backwashing the filters. Traditionally, the waste-water and sludge were discharged to the nearest water course with little effort given to treatment. With recent environmental concern being at the forefront and with increasing volumes of water treatment plant sludge being produced yearly, a move is afoot to handle this sludge in a less environmentally damaging fashion. Little can be done on an economical basis to recover the inorganic salts from the sludge; the attention has been focused on reducing the volume of sludge to be handled for ultimate disposal. One method that has been used to condition the sludge in preparation for dewatering is freezing and thawing.

Bishop and Fulton have suggested lagooning and freezing for the disposal of water plant sludge.(7) The lagoons would be used as both settling and thickening facilities. They suggest that two lagoons be used, each with a large enough surface area that the depth of sludge poured thereon during the summer could be completely frozen during the following winter. During transition periods one lagoon would be used exclusively as a freezing facility while the other lagoon would receive fresh sludge. Fall decanting of supernatant would reduce the volume of sludge to be frozen during the winter. The authors predict that sludge could be accumulated over several seasons and the bearing strength would be sufficient to have the sludge removed with a front-end loader. Although cost figures were not presented, it was suggested that the cost would be very little in comparison to the cost of an overall filtration plant, providing land is available. This technique is feasible economically only if natural freezing can be utilized. The authors contend that it is the water of hydration, contained in the aluminum hydroxide holding the enmeshed turbidity particles, that is released by freezing. The total solids concentration of the sludge was increased from 3.5 to 17.5 percent and a significant volume reduction occurred after one freeze-thaw cycle. When the sludge thawed it did not return to its original gelatinous state; the sludge drained and dried to a consistency that could be easily handled. The freezing rate was not mentioned and was probably not considered to be an important factor since such good results were obtained even while ignoring it.

Fulton describes a New York community water treatment plant[18] which is presently using the freeze-thaw method of sludge conditioning. Rather than constructing lagoons, this design simply used an existing headrace of an adjacent abandoned power plant. The headrace was divided into two sections in order that freezing could be effected during the autumn transition period. Consolidated solids would also be pumped from one basin to the other for freezing in the winter time. Freezing will be effected in layers as dictated by volumes withdrawn from the first to the second basin. Again, it is stated that freezing changes the jelly-like consistency of aluminum hydroxide suspension to a readily settleable granular form. The theory of dewatering and freezing rate was not discussed in this paper.

Benn and Doe[4] used artificial freezing in an attempt to reduce the quantity of sludge to be handled from coagulation and backwashing procedures at a complete water treatment plant in England. Although good results were achieved, the authors concluded that the process was uneconomical and would always be so unless larger volumes of sludge could be frozen artificially. Further, they stated that flash freezing will not produce the same effect as slow freezing. Repeated stresses on the freezing tank necessitated heavy construction, which caused high capital cost and periodic replacement of components, which resulted in significant operating cost. With the freezing apparatus used, the authors stated that pure ice crystals began to grow on the sides of the freezing vessel and grew toward the center. The sludge is forced toward the center and is eventually trapped between coalescing ice crystals. Ultimately the sludge is either dehydrated or enmeshed in the ice. The resulting pressure reportedly compresses the sludge into fine hard grains. During thawing the grains of sludge fall through the supernatant to the bottom of the container. The authors report that the only limitation on the process is that freezing proceed slowly enough to allow pure ice crystals to form. When the sludge has been frozen and separated it will not revert to its original form. A change in state from gelatinous sludge to a texture resembling coffee grains was reported; the resultant material has good bearing strength. This is an important consideration if ultimate disposal is to be to a landfill.

C. Sewage Sludge Dewatering

Sewage sludge dewatering has long been a problem confronted by sanitary engineers. It has been found that dewatering has often been enhanced by using a conditioning process before the actual dewatering step. The more common conditioning processes are heat addition, coagulant addition, elutriation and thickening.[1],[22] Over the past twenty years some interest has been shown in freeze-thaw sewage sludge conditioning although the beneficial effects of freezing sludge were exhibited as early as 1929.[15] It is generally conceded that artificial freezing cannot compete economically with more established methods of sludge dewatering such as polymer addition followed by vacuum filtration. Although many investigators have suggested that natural freezing would be a feasible sludge conditioning process, it is rarely used. In fact the literature surveyed turned up only one installation[23] where sludge is frozen on a routine basis. Even at this location freezing occurs only incidentally and was not stated to be an integral part of the dewatering process.

In 1929, Babbitt and Schlenz[15] reported on the effect of freezing on the drying of sludge. The experiment happened quite by accident when samples of fairly well digested sludge were placed on two sets of drying beds and the outside temperature turned cold. Upon thawing the beds dried without releasing any considerable amount of free water. The final dried sludge was found to have a dry spongy appearance, little cohesion, was easily pulverized, had no odor, and separated easily from the sand on the bed. The authors found that freezing alters the draining qualities of sludge and allows the entrained water to separate very quickly during thawing. The final moisture content was much lower in the sludge that had been frozen than sludge which was dried without freezing. From microscopic examinations it was theorized that the effect of freezing was to overcome the attraction of the colloidal particles for water and to permit this water to drain rapidly upon thawing. In conclusion the authors stated that it was not only feasible, but advantageous to draw sludge onto the drying beds in cold weather.

In the late 1940's Clements, Stephenson and Regan[16] did extensive experimentation with the freezing of primary, digested and activated sludge. They also experimented with the addition of chemicals prior to freezing in order to investigate their effect on subsequent sludge dewatering. All freezing was done by artificial means. Their conclusions are summarized as follows:

1. The settlement of all types of sewage sludge is promoted by freezing.

2. Settlement is accelerated by freezing with chemicals, but the percentage settlement at the end of an hour is approximately the same whether chemicals are used or not.

3. Filtration, after freezing with chemicals, is remarkably accelerated.

4. The chemicals used were chlorinated ferrous sulfate, chlorine gas and aluminum sulfate, and doses were up to 1,000 mg/l of the active ion.

5. The best results were obtained by the use of aluminum sulfate, dry solids production reaching 350 lbs/ft./hr.

6. Complete freezing is essential: freezing must be fairly slow: "flash" freezing is ineffective.

7. Some saving of latent heat of fusion is practicable in a suitable installation.

8. The method of thawing is immaterial, as long as it is not associated with vigorous agitation.

9. The supernatant liquids on settlement are, on an oxygen absorption basis, not much worse than ordinary sewage.

The authors theorized that, in freezing, water is separated from colloidal matter and an ice network is formed, in the centers of the meshes of which are colloidal particles. If these particles are not readily dispersible in water (as is sludge) a system is formed on thawing which is irreversible. Slow freezing is more effective than fast freezing because it leads to a relatively small number of crystallization centers with comparatively large ice crystals. Fast freezing produces a much larger number of crystallization centers leading to the formation of a glass composed of microscopic crystals. Adding chemicals was said to cause a continually increasing concentration of electrolyte in the interstitial liquor surrounding the colloidal sludge particles, as water is abstracted to ice crystals. Because the colloids are negatively charged, the strongly electropositive charges on the electrolyte would neutralize these colloids and irreversible precipitation would occur. A dehydration effect was also attributed to pressure produced during slow freezing.

In 1953 Bruce, Clements and Stephenson published a paper[24] describing further work on the sludge freezing process. Sludge was artificially frozen in cans lowered into brine tanks. Upon thawing dewatering was effected on various filter media. Elutriation was tried and yielded negative results. Dewatering was also attempted in a centrifuge; the results in concentrating sludge were not encouraging. It was also found that the digestion of activated sludge did not improve its response to freezing with chemicals. Some tests were conducted on the availability of nitrogen in sludges; low values were found and it was suggested that the slow-acting nature of a substantial part of the nitrogen in sewage sludge may account for its unpopularity as a nitrogenous fertilizer. Presumably the conversion of ammonia to nitrates is slow. A loss in nitrogen was experienced through sludge digestion.

Coackley commenced research on the dewatering of sewage sludges at University College, London in 1950.[17] His initial program was to study the effect of ultrasonic vibrations, freezing and the action of direct current on the dewatering of sludge. After Clements, Stephenson and Regan published their paper[16], work on the freezing process at University College was stopped. The results obtained prior to curtailment of the program were in agreement to those published by Clements, et al.[16] Coackley studied the freezing process microscopically and the observations showed that the ice crystals pushed the sludge particles together, making larger aggregates; no evidence was found for the theory that cells were burst open, liberating water.

In 1962 Bubbis published a paper regarding the operation of sludge drying lagoons at Winnipeg, Canada.[23] The normal procedure at these lagoons is to apply a 10-inch layer of digested sludge, allow it to stand for 14 days and then decant the surface liquor. When the lagoon is filled, the sludge is removed with a heavy equipment scraper. Freezing was mentioned only incidentally in that lagooning is also used in the winter time, which experiences extremely cold temperatures. The author suggested that the sludge could be removed from the lagoons in the winter, using a ripping and scraping procedure.

In 1966, Agardy and Kiado discussed the effects of refrigerated storage on the characteristics of waste.[25] The discussion included effects of simple cooling and freezing, which was done at -5°C. They found that the colloidal character of a sample will be altered by the freezing and thawing process and coagulation will occur. They contend that the increase in suspended solids and volatile suspended solids as a result of freezing is a clear indication of the colloidal nature of many waste constituents.

Andrews, in 1967, published a comprehensive treatise on sludge treatment and disposal.[22] He mentioned that, in Winnipeg, frozen sludge is removed from beds and placed on concrete pads where it rapidly dewaters in spring. He suggests that the effect of freezing is to overcome the attraction of the colloidal particles for water and this permits the water to drain rapidly upon thawing.

A study of sludge handling and disposal done by Burd in 1968[1] stated that sludge frozen by nature and later thawed in sand drying beds or lagoons had good dewatering and soil-conditioning properties. He suggests that the thawed sludge is stable and dewaters rapidly if provisions are made for water drainage. Artificial freezing can aid in sludge dewatering; however, it will never be economical except in very isolated cases. Problems were reported to be encountered in high operating costs, partially due to the need for dewatering equipment to handle high production rates.

In 1970, the Federal Water Quality Administration also reported briefly on the freezing process for sludge conditioning.[19] It was stated that freezing disrupts the cell walls retaining the internal moisture in sludge and allows the water release and drainage. Slow and complete freezing was reported to be necessary for good dewatering results. It was also reported that 28 BTU were required to lower the temperature of one pound of sludge from 60°F to 32°F and 142 BTU were then required to freeze this pound of sludge. Again it was pointed out that artificial freezing would require greatly improved economics to be feasible in prototype installations.

An extract translated from Japanese[14] considered freezing temperatures, freezing time, thawing cycles and standing time after thawing. It was concluded in this brief article that in sludge freezing there exists an optimum product of freezing temperature and time.

In 1970 Katz and Mason used freezing methods to condition activated sludge prior to dewatering.[13] The results indicated that high solids production rates in the order of 55 lb. of dry solids per square foot per hour were obtained during vacuum filtration of freeze-conditioned activated sludge. The filtrate and filter cake quality produced were equivalent or better than that produced from conventional vacuum filtration operation. It was also concluded that freeze-conditioned sludge can be dewatered by gravity drainage using wire screen cloth (40-80 mesh). The authors theorize that the conditioning effect produced by freezing is a result of dehydration and pressure exerted on the sludge particles by the ice structure. Further, they point out that the freezing rate is important because it affects the dehydrating and pressure-producing properties of the ice structure.

Cheng, Updegraff and Ross[26] experimented in 1970 with freezing sludge via the film-freezing principle in which freezing time and the temperature driving force are greatly reduced over those used for the extended freezing process. They contend that the addition of at least 20 mg/l of aluminum [as $Al_2(SO_4)_3$] is necessary for efficient dewatering. The integral difference in using the film-freezing principle is that a very thin ice film is used; this thin ice film allows the rapid removal of heat even at small temperature differences due to a large thermal admittance. An external heat transfer mechanism, the cooling bath stirring rate, controls the process. Samples of primary, activated and digested sludge were used in the experiment. After freezing and thawing the sludge was filtered and gave solids production results similar to those obtained by Clements, et al.[16] The authors felt that this method will improve the economics of artificial freeze-conditioning of sewage sludge.

As a co-operative effort with the project for which this thesis is written, Osterkamp performed experiments at the University of Alaska in the early spring of 1971.[20] His attentions were focused directly on the structural features of wastewater sludge ice. He utilized ambient air temperatures, internally controlled by insulation and a heat tape, to effect one-dimensional freezing of thick activated sludge. The experiments showed that the ice structure was cellular in nature. The mechanism of improved dewatering after freezing was explained in three steps. Firstly, the growth conditions of the ice and the presence of ionic impurities cause the formation of a cellular interface morphology. Secondly, the sludge particles and other impurities are mechanically trapped in the grooves between these cells, forming sludge pockets, which results in coagulation of the sludge particles. Thirdly, dehydration of the coagulated sludge particles occurs as the sludge pockets are subjected to lower temperature and the water in them freezes out. Reportedly, these processes are irreversible. Osterkamp reported that, when the ice matrix melts, the coagulated sludge particles settle rapidly and leave a relatively clear supernatant. He explains the poor results due to quick freezing are due to the failure of a cellular interface to develop. Dehydration is also retarded during a quick freeze. Super cooling is reported to be an exception to the failure of quick freeze methods due to the ordering of the water molecules in the liquid phase. The author contends that coagulation is the primary process in the success of the sludge freezing technique while dehydration is a secondary process.

D. Drainability

Nebiker, Sanders and Adrian[27] investigated sludge dewatering rates in 1969 and reported that initial solids content, depth, specific resistance, coefficient of compressibility and filtrate viscosity are the important parameters affecting the time required for dewatering.

Factors affecting drainability of activated sludge were discussed by Randall, Turpin and King in 1971.[28] They suggest that there are two steps to dewatering:

1. Applied sludge settles and compacts on drying bed.
2. Drainage pores develop in the settled sludge layer.

There are several factors affecting drainability but solids concentration reportedly has the greatest effect. The authors state that, in general, the variation in sludges depends on how disperse the microbial solids are and the effect of sludge property on drainability usually depends on how it affects dispersion. In conclusion they suggest that none of the standard tests presently utilized are sensitive enough to measure dispersion.

E. Summary

Water and sewage effluent purification by the freeze-thaw method is concerned with the rejection of dissolved materials, both organic and inorganic, by pure ice crystals growing in a mother liquor. The rejection phenomenon is relevant to the mechanism by which sludges are conditioned by freeze-thaw prior to dewatering. However, with sludges, attention is focused on the suspended and colloidal material whose concentration is at least 10 times that of the dissolved material. Osterkamp[20] alluded to the importance of a certain ionic strength in order that a cellular interface morphology would form. Otherwise dissolved impurities were not of any concern to the investigators of the freeze-thaw process insofar as it pertained to sludges.

The theories presented for the freeze-thaw mechanism which enhances dewatering were often vague and usually speculative. There seems to be no clear cut distinction between the theories offered for water treatment plant sludge and sewage treatment plant sludge. There is little support for the theory that freezing disrupts cell walls and allows water to drain away freely upon thawing. Intensive investigations did not support this theory. Osterkamp[20] along with Clements, Stephenson and Regan[16] did intensive work and offer the most coherent theories regarding the mechanism of sludge dewatering. These investigators contend in a convincing fashion that the mechanism involves:

1. Coagulation of the sludge particles due to the crystal growth of ice.
2. Dehydration of the trapped sludge particles due to freezing.
3. Release of the water upon thawing.

Coagulation appears to be the primary mechanism. The physical and chemical properties of freezing sludge, frozen sludge, thawing sludge and thawed sludge, closely observed during the research project for which this thesis is written, also support the explanations of Osterkamp[20] and Clements, et al.[16] These observations will be explained further in Chapter VI.

The effect of the freezing rate was ignored by some investigators and touched lightly by others. A relatively slow freeze appears to be necessary especially to achieve large crystals and good coagulation. An increase in the freezing rate would likely reduce the coagulation process before it would affect the dehydration process. Too quick a freeze would interfere with both mechanisms.

A third mechanism which is likely of less significance than coagulation and dehydration was suggested by some investigators.(22),(15) This theory propounds that freezing breaks the attraction of the colloids to water and allows the water to drain freely upon thawing. This theory would suggest that sewage sludge is, in fact, a hydrophilic colloidal dispersion and that freezing effects electrokinetic changes which destabilize this dispersion. None of the investigators pursued this theory to any degree but it appears to be noteworthy.

CHAPTER III PROJECT DESCRIPTION

The logistics encountered while conducting a research project outdoors, during January, February and March of any given year in sub-Arctic Alaska, are rigorous to say the least. Loss of efficiency in manpower due to a combination of low temperature, excessive snowfall, long periods of ice fog and short daylight hours was experienced during this project. The necessity of minimizing required hours of labor outdoors during these months was fully appreciated. Similarly, equipment and operations utilized outdoors during the sub-Arctic winter should be kept as simple and maintenance free as possible. It was obvious that intricate, sophisticated equipment would be quite useless during the most adverse of the environmental onslaughts.

A. The Model Sludge Drying Beds

Nine model sludge drying beds were constructed indoors during the month of January, 1971. These were arranged on the site as shown in Figure 3; the beds were underlain by a six-inch gravel pad which was placed on top of packed snow. The sludge was poured into the beds in three runs according to the following schedule:

Run	Bed	Nominal Depth of sludge	Insulated	Date Poured
1	A	6"	no	
	B	6"	yes	February 12, 1971
	C	18"	yes	
2	D	6"	no	
	E	6"	yes	February 27, 1971
	F	18"	yes	
3	G	6"	no	
	H	6"	yes	March 19, 1971
	J	18"	yes	

Each run, therefore, involved one six-inch uninsulated bed, one six-inch insulated bed and one 18-inch insulated bed. The depths refer to the nominal depth of sludge; overpour was used to compensate for sand infiltration. The actual final depths of sludge at the time of freezing are shown in Table 1. Figure 4 shows a diagram of a typical 18-inch bed. None of the six-inch beds were provided with the four-inch drainage tile. Three of the six-inch beds (A, D, G) were constructed without the two-inch polyurethane insulation. The insulation was used in an effort to simulate one-dimensional freezing during the early stages of freezing.

Prior to pouring of the sludge the sand in the beds was soaked with water and allowed to freeze; this was done to minimize the infiltration of the sludge into the sand prior to sludge freezing. The beds were also fitted with thermocouples prior to the pouring of sludge.

Figure 6 illustrates the appearance of the sludge beds in the winter time. Figure 7 gives a view of the site interior. The inside of Bed H is shown in Figure 9; the frozen sand and thermocouple dowel are to be noted.

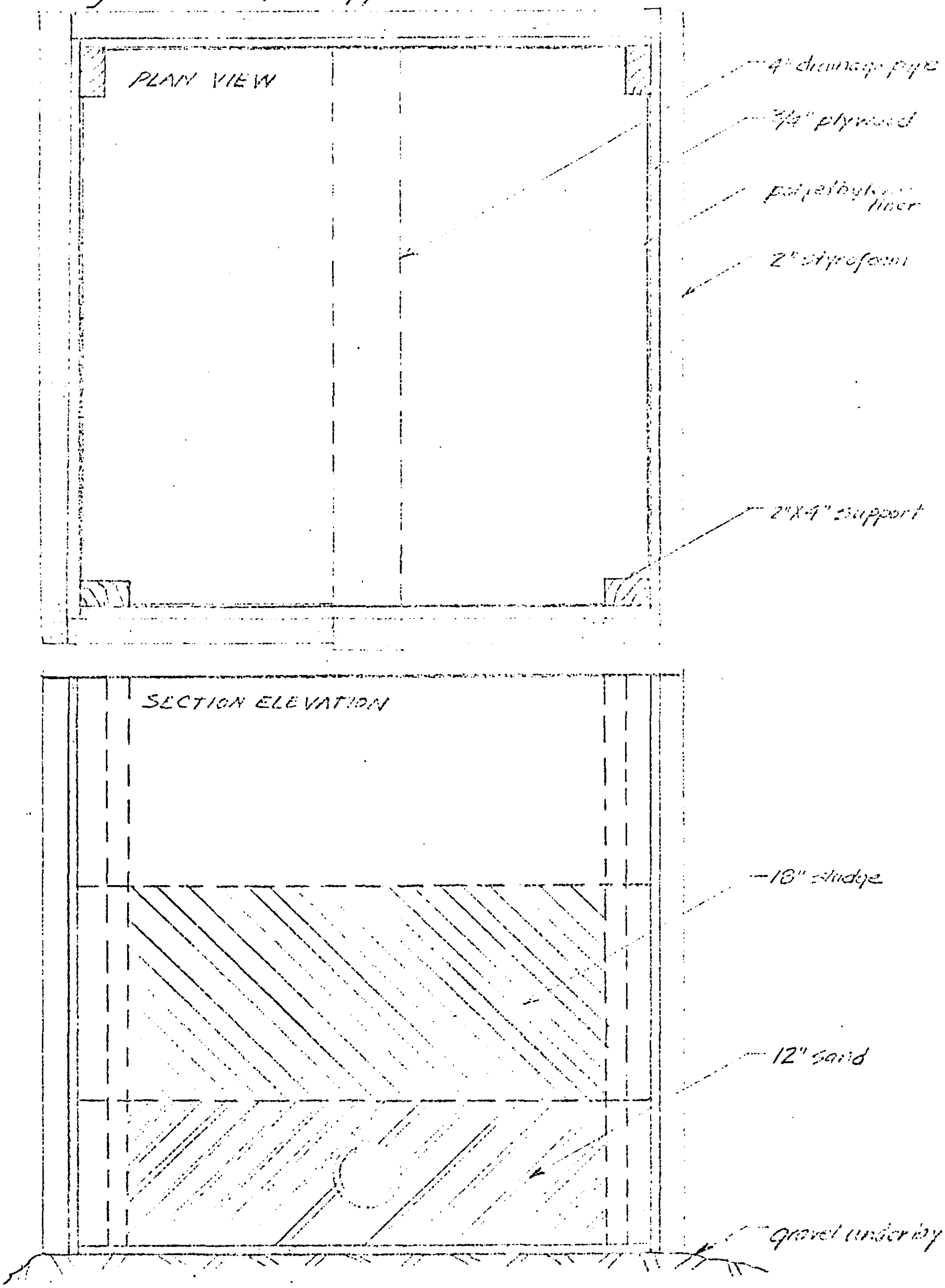
B. The Site

In order to minimize variables due to weather, the beds were protected from precipitation by means of a 24' x 24' canopy. This structure consisted of 4" x 4" framed members supporting an aluminum roof. As shown in Figure 1 the site was aligned in a north-south direction. During the thaw period the morning sunshine was directed on Beds G and H; J was shaded. The early afternoon sunshine reached the southern portion of C, F and J; the late afternoon sunshine reached the western portions of A and B. Beds D and E received no direct radiation energy from the sun.

Table 1
INITIAL DEPTHS OF SLUDGE

Bed	Depth (inches)
A	9.375
B	6.9375
C	21.8125
D	6.4375
E	7.5625
F	22.8125
G	7.625
H	6.0
J	18.75

Figure No.4 - Typical 18-Inch Bed Construction



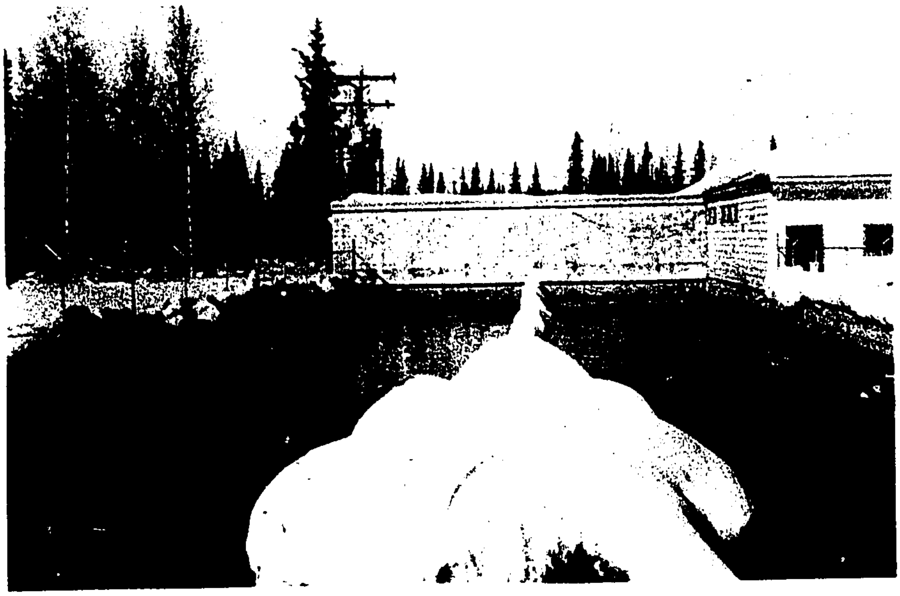


Figure No. 5 - Half of the Oxidation Ditch

Figure No. 6 - Model beds in wintertime

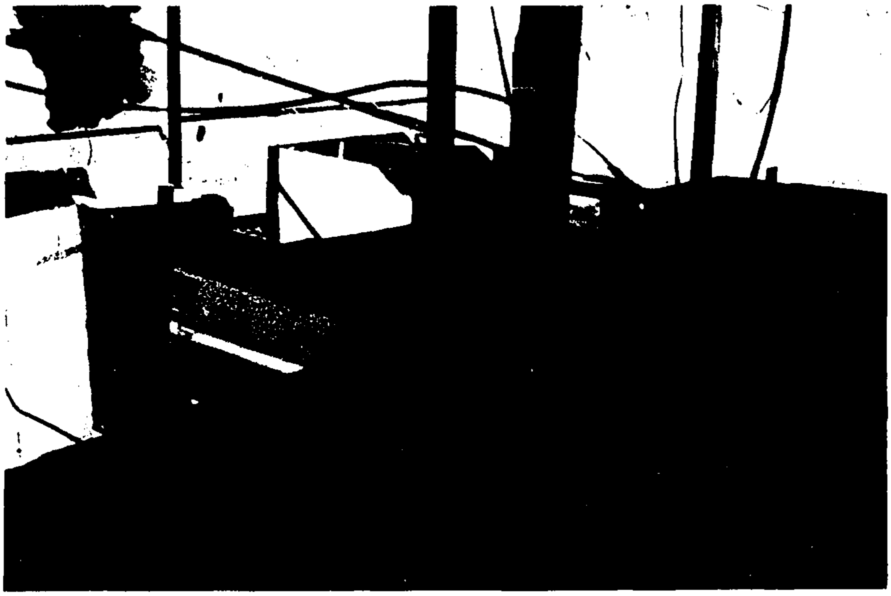


Figure No. 7 - Site interior NW from Bed J

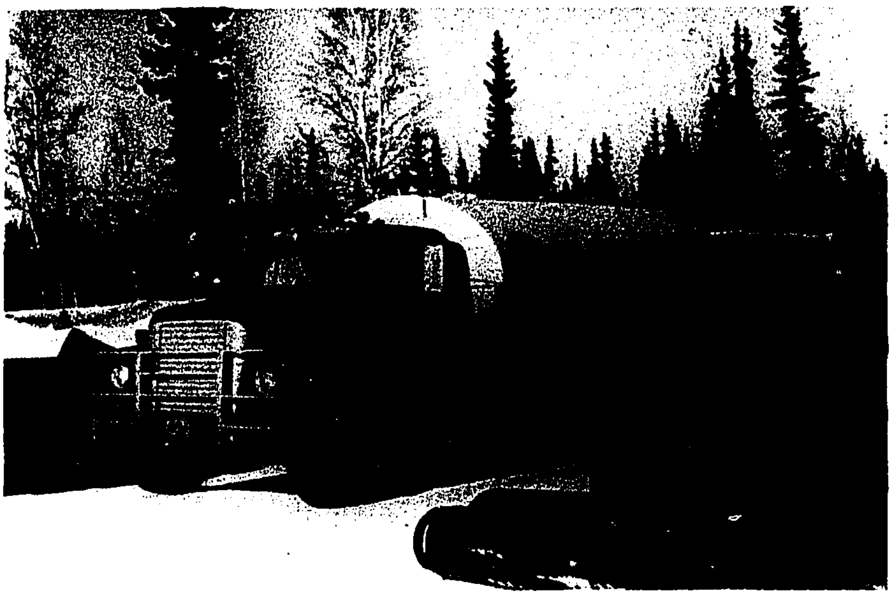


Figure No. 8 - Conveyance of sludge to beds

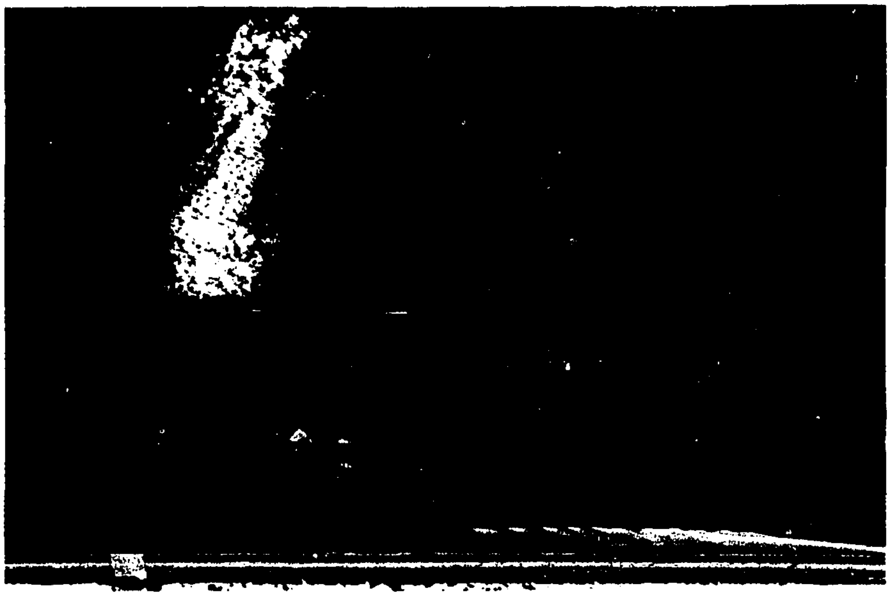


Figure No. 9 - Insulated six-inch bed awaiting sludge

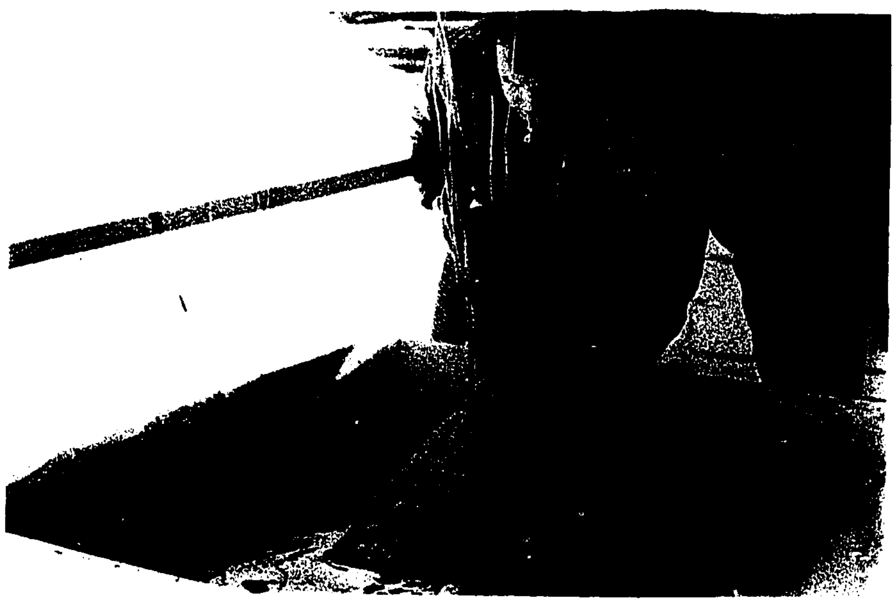
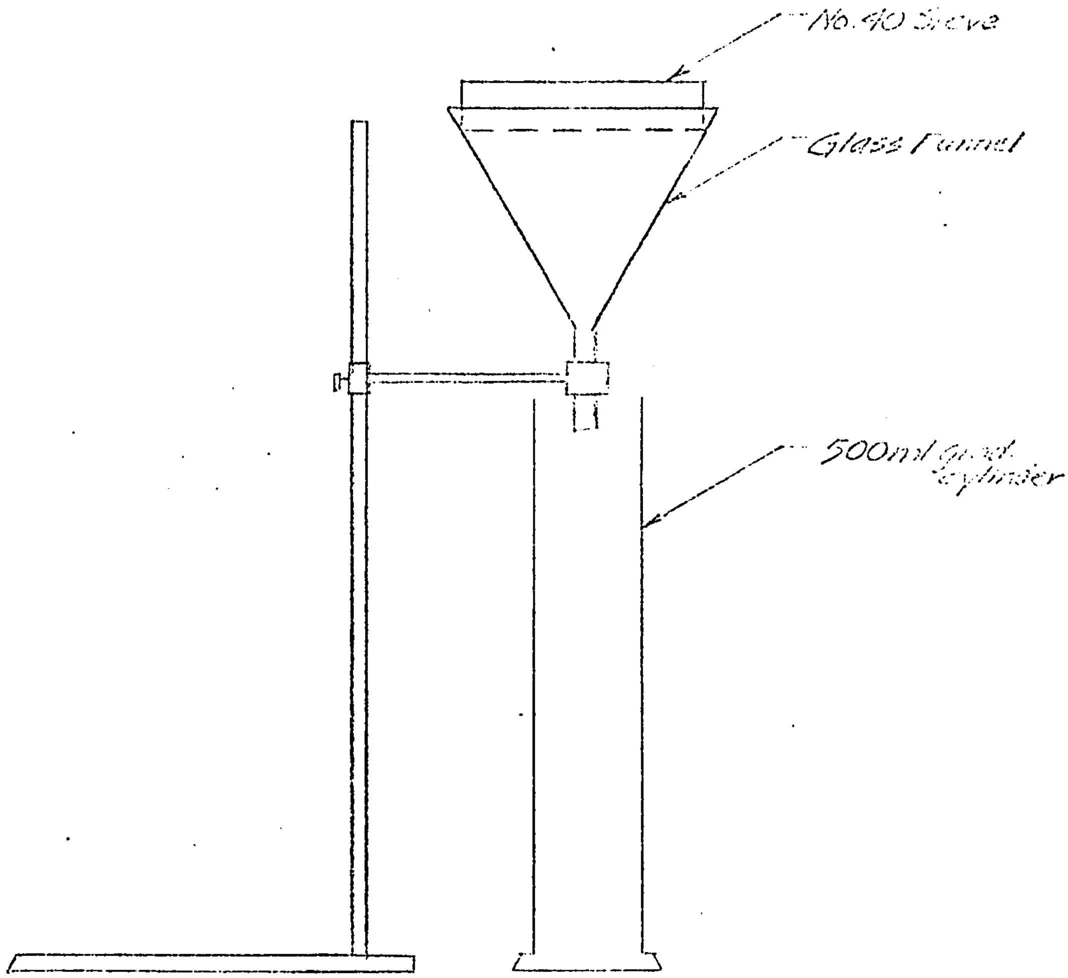


Figure No. 10 - Pouring and sampling sludge in Bed G

Figure No. 11 Drainability Apparatus



1000 ml sludge poured onto 615 cc of sand on sieve.

The canopy withstood the winter stresses well but sagged somewhat during the spring thaw. Figure 5 illustrates the site in the winter time, while Figure 54 shows some of the effects of the spring thaw.

C. Temperature Recording

Thermocouples were placed in the beds prior to pouring sludge for each run. The thermocouples were run approximately 160 feet to a recorder housed in the sedimentation tank room of the sewage treatment plant. For the first two runs a Leeds and Northrup 12 point Strip Chart Recorder (Speedomax H) was utilized to continuously record temperatures during the freezing period. A Honeywell Electronik 15 Multipoint (24 channels) Strip Chart Recorder was used to record third run temperatures during freezing, the frozen stage and the thawing period.

Simple dowels driven into the sand and electricians' tape were used to affix the thermocouples to the centerline. Wall readings were assured by fixing the thermocouples to the wall proper. Placement of thermocouples is described, along with the hourly temperature readings in Tables 17, 18 and 19. The recorders and thermocouples were checked and calibrated in the laboratory prior to field use. In spite of this, some thermocouples failed in the field, namely thermocouple #5 in the second run and thermocouples #5 and #20 in the third run. Channel 12 in the Leeds and Northrup recorder was inoperative for the first two runs. Figure 49 illustrates some thermocouples protruding from a freshly poured bed of sludge. An array of thermocouples are also shown in Figure 55 during the initial stages of thaw in Bed H.

D. Pouring Sludge

Activated sludge was drawn from the sedimentation tank of the College Utilities biological waste treatment plant adjacent to the experimental units. A flow diagram of this process is shown in Figure 2. The sludge was pumped into a tank truck, shown in Figure 8 and poured via a four-inch flexible hose into the prepared beds. The time span between sludge withdrawal from the sedimentation basin and pouring into the beds never exceeded 30 minutes. A photograph illustrating the pouring and sampling of the sludge during the third run represents Figure 10.

The sludge was drawn from the sedimentation tank such that progressively thinner sludge would be used for each of the three runs. The thickness of the raw sludge was crudely controlled by plugging the sludge return line at the outlet of the sedimentation basing (See Fig. 2) and by varying the elevation of the sludge intake line in the sedimentation basin while sludge was being pumped to the tank truck. Figure 49 illustrates some freshly poured sludge and the protruding thermocouples.

E. Sampling Procedures

As shown in Figure 10 raw sludge was sampled during the sludge pour, directly from the flexible hose. In order to insure a representative sample, two four-liter samples were collected for each bed. One sample was taken at the beginning of the sludge pour into the bed and one was taken at the end of the pour into a bed. Six raw sludge samples were therefore taken during each run. These samples were taken immediately to the laboratory and analyzed; this procedure was followed to obviate sample storage and its attendant problems. The sample taken at the beginning of the pour into Bed D, for example, would be denoted D-1 while the sample taken at the end of the pour into Bed D would be labeled D-2. Throughout the results, tabled hereafter and referred to in Chapters V and VI, the sample numbers refer to the sampling time of raw sludge. There is one exception, however, in the core analyses. In this case and this case only, all the result of which are included in Table 28, D-1, D-2, etc. refer to dates of frozen sludge core collection.

After the sludge had frozen and remained in the frozen stage for a number of weeks, cores were removed from the beds. This was effected utilizing a coring device and a chain saw. The chain saw, albeit unscientific, was much more functional after the ice had begun to weaken during the warmer weather. Several cores were taken from the six-inch beds in order to check whether prolonged storage in the frozen state had any effect on sludge quality. Single cores were withdrawn from the 18-inch beds; a core hole in Bed F is shown in Figure 51. Freshly frozen and heaved sludge in Bed A is illustrated in Figure 50. Evidence of circular core holes and heaving, along with a psychrophilic mold, are depicted in Figure 52 which is a view of Bed A during warmer weather.

After sampling the cores were wrapped in polyethylene bags and quickly stored in a laboratory freezer until analyses were commenced. The storage temperature was -18°C.

Photographs were taken throughout the field program in order to document observations. Photographs of undisturbed cores are included in Figures 36, 37, 38, 39, 40 and 41.

Relative humidities were measured using a Bacharach Sling Psychrometer.

CHAPTER IV EXPERIMENTAL PROCEDURES

In keeping with the overall objectives of this project, as many analytical measurements were performed as time permitted. The chemical parameters, as measured in the laboratory were relatively routine; the physical day-to-day monitoring done in the field proved to be more rigorous. For the purpose of discussion the procedures are divided into raw sludge analyses, frozen sludge core analyses, field monitoring and miscellaneous experiments.

A. Raw Sludge Analyses

As stated in Chapter III, six raw sludge samples were collected at the outset of each run. These samples were transported immediately to the laboratory for analyses; thus, storage of the samples was not necessary. These raw sludge samples were subjected to the following analyses:

BOD
COD
pH
Total Solids
Total Volatile Solids
Settleable Solids
Physical Condition

Dilutions were done prior to the BOD and COD analyses. All procedures were performed in accordance with Standard Methods for the Examination of Water and Wastewater - 12th Edition.[5]

B. Frozen Sludge Core Analyses

The cores were sampled from the model beds between March 16 and April 10 as outlined in Table 28. The core samples were stored in a laboratory freezer until the week of May 17-22, during which they were analyzed. The cores were cut into two or thee-inch sections, each of which were analyzed separately. Three separate phases of the core sections were studied after thawing was completed at a laboratory temperature of 23°C. Those phases were the "supernatant" or the water which drained off the thawed sludge, the dewatered solids or the coagulated mass remaining after gravity drainage was complete, and the water-sludge mixture which resulted from stirring the yet unanalyzed, thawed core section. Thawing was effected in 2,000 ml. beakers which are illustrated in Figures 42 and 43. The numbers following the core samples number indicate the depth in inches of the sample from the surface of the sludge bed. The analytical results are outlined in Table 28 and are enumerated as follows:

Supernatant - pH
BOD
COD
Suspended Solids
Volatile Suspended Solids
Total Solids
Total Volatile Solids

Dewatered Solids - Total Solids
Total Volatile Solids

Water-Sludge Mixture - Total Solids
Total Volatile Solids
COD

Limited quantitites of sample, especially supernatant, did not allow the completion of all the tabled analyses for all samples. Difficulty was encountered sampling the supernatant representatively because small pieces of rejected solids were difficult to separate from the liquid portion. In most occasions there was not enough sample to run replicate analyses.

Settleable solids tests were also conducted on the two 18-inch cores, C and F. Bed J did not completely freeze and therefore a full 18-inch sample was not obtained. The clarity of the sample obtained obviated the settleable solids test. The supernatant from the settleable solids test was analyzed for pH, BOD, COD, Suspended Solids and Volatile Suspended Solids.

Noteworthy physical characteristics, such as odor and color were observed on all core sections.

The remains of the core sections of C2, E3, and H1 were respectively mixed to comprise altered samples C2, E3 and H1. These were subjected to drying for 18 hours on three inches of coarse grained sand contained in coffee cans. Total solids and total volatile solids analyses were conducted on the dried sludge.

Drainability tests were run on undisturbed aliquots of cores C and F. The test is described in Table 28 and was adapted from Babbitt and Schlenz.[13] The apparatus used in the arbitrary drainability test is shown in Figure 11.

Further explanations of the frozen sludge core analyses are contained in the addendum sheet to Table 28.

C. Field Monitoring

The field installation was visited daily from February 12 until May 26. From May 26 until June 17 the site was inspected at least three times weekly. June 17 was considered the end of the field monitoring program.

Up until the beginning of the thaw period, which was generated quasi-continuously from April 15 onwards, the field visits consisted simply of checking the thermocouples and recorder, changing chart paper and observing the physical condition of the sludge beds and the site structure. When the period of thaw set in the inspection visits included the following procedures:

1. Checking the recorder and thermocouples
2. Observing the depth of the sludge
3. Observing and noting the condition of the sludge
4. Observing and noting site conditions
5. Measuring the horizontal and vertical thawing in the beds

During the period from April 24 to June 29, 130 samples of thawing, and drying sludge were collected from the beds and analyzed for total solids and total volatile solids.

Afternoon relative humidity, weather conditions and air temperature were monitored daily from May 6 to June 2 in an attempt to determine approximate evaporation rates at the site.

On June 2 samples were collected from beds C, F and J and submitted to the Agricultural Sciences Laboratory, operated by the University of Alaska in Palmer, for nutrient analyses. The results of these analyses were discussed with the District Agricultural Agent, Cooperative Extension Service, University of Alaska.

Liquid samples were collected from the top of the beds whenever a sufficient volume of liquid was present. This occurred only on three occasions, those being April 17, April 20 and April 23. On these dates liquid was available only from beds H and J, which received direct sunlight. These samples were subjected to the following analyses:

pH
BOD
COD
Total Solids
Total Volatile Solids
Suspended Solids
Volatile Suspended Solids
Dissolved Solids (Calc.)
Physical Characteristics

Samples of ice were collected from Beds C, F, G, H and J during late April in order to document the difference in the ice quality of these beds. The samples were taken from the top 1-1/2 inches of the respective beds. These samples were analyzed for the following parameters:

pH
BOD
COD
Suspended Solids
Volatile Suspended Solids
Total Solids
Total Volatile Solids
Dissolved Solids (Calc.)
Physical Characteristics

It should be noted that a seed was not used, and did not appear to be required, to perform BOD determinations on these ice and liquid samples which were collected after the sludge had been frozen and kept in the frozen state for a minimum of one month. This is stated in view of the good BOD recoveries found in these samples as compared with BOD's done on the supernatant of settleable solids tests done on raw sludge.

Considerable temperature data were collected on the strip chart recorders. For the first two runs (February 12 and February 27) temperatures were monitored only until the sludge had frozen. During the third run the temperature was monitored during freezing, while the sludge was in the frozen state, during thawing and for a short time after thawing was complete. Temperatures from the strip chart were tabulated on an hourly basis during the first two runs. Temperatures from the third run (March 19) were tabulated on an hourly basis only during critical periods, which included the freezing and thawing events. During the period in which the sludge was frozen the temperatures were tabulated on a schedule varying from once per day to once every four hours. All individual hourly readings and less frequent readings were arithmetically averaged into average daily temperatures. Occasional gaps appear in the data where workmen inadvertently unplugged the recorder or where the chart paper expired before a routine inspection.

Computations were made pertaining to freezing and thawing time, sludge depth versus solids concentrations, and total sludge depth as a percentage of original applied depth, during the thaw.

Photographs were taken during important phases of the field work to document environmental conditions as well as to show physical characteristics of the sludge.

D. Miscellaneous Experiments

Several experiments were conducted with raw sludge that was remaining after the routine analyses, described in Part A of this chapter, were completed. Raw sludge from Run 1 was viewed under a 3D Microscope at 10.5 power.

Run 2 raw sludge was subjected to freezing in a laboratory freezer at -17°C. The freezing was effected in five pound coffee cans to simulate a quick, three-dimensional freeze. The frozen samples, F2, F1 and D2 were thawed at 25°C; the supernatant was analyzed for BOD, pH, COD and suspended solids while the settled sludge was subjected to total solids and total volatile solids determinations. The thawed samples were then mixed to perform a settleable solids test on each. The samples were then remixed and placed on small sand beds and dried for three days. Analyses performed after drying were BOD, COD and Total Solids.

In addition to the routine raw sludge analyses of Run 3 were analyses of the supernatant, from the settleable solids test, for BOD and suspended solids. Part of the excess volumes of samples of raw sludge from Run 3, H1, G1 and G2, were dried for 24 hours on sand and analyzed for total solids and total volatile solids. The remaining portions of raw sludge samples, G1, J1 and J2, were frozen in a laboratory freezer at -17°C. The extra volumes of G2, H1 and H2 were dosed with 20 mg/l of alum and also frozen at -17°C. The freeze simulated a quick, three-dimensional technique. These six samples were thawed at 24°C and then subjected to the settleable solids test.

Aliquots of the supernatant from this test were then analyzed for the following parameters:

pH
COD
BOD
Total Solids
Total Volatile Solids
Suspended Solids
Volatile Suspended Solids
Dissolved Solids (Calc.)
Physical Characteristics

During the thaw additional raw sludge samples were collected from the sedimentation basin at College Utilities and subjected to the drainability test. Aliquots of these samples were frozen in the laboratory freezer at -17°C, then thawed at 23°C and subjected to the drainability test. This was done to construct a family of drainability curves which would allow comparison of results obtained from raw sludge, lab-frozen sludge and field-frozen sludge.

A brief attempt was made to correlate raw sludge solids concentrations to specific gravity of the sludge.

CHAPTER V PRESENTATION OF THE DATA

Because of the voluminous nature of portions of the data, some is presented in the body of the thesis while other parts are included in the Appendix. Generally, graphical representatives are included in the body of the thesis while tabulated material is found in the Appendix. Where graphical representations were not constructed the tabulated data is included in this chapter. The purpose of this chapter is to present the data in an orderly manner; the data are discussed in depth in Chapter VI. For clarity in this presentation, the data are divided into four general sections: raw sludge data, frozen sludge core data, field data and miscellaneous data.

A. Raw Sludge Data

Tables 2, 3 and 4 describe the physical and chemical characteristics of the raw sludge collected at the outset of the first, second and third run, respectively. An analysis of the supernatant from the settleable solids tests performed during the third run is the basis of Table 4A. Figures 12, 13 and 14 illustrate the results of the first run settleable solids test; Figures 15, 16 and 17 pertain to the second run settleable solids and Figure 18 shows the settleable solids test results from the third run.

The results of the drainability tests performed on random samples of raw sludge are included in Table 16, which is part of the Appendix; the graphical representation is incorporated in this chapter as Figure 19. In this figure the raw sludge drainability is compared to lab-frozen sludge drainability.

Table 2
RAW SLUDGE BEDS A,B,C

Run 1 February 12, 1971

Sample	pH	COD mg/l	BOD mg/l	BOD/COD	Solids % Total	Solids % Vol	Settleable Solids (ml) 1/2 hr	1 hr	3 hr	6 hr	8 hr	20 hr	24 hr
A1	6.7	52,380	14,100	0.269	4.94	75.35	1000	1000	975	960	948	905	905
A2	6.6	62,280	13,800	0.220	5.79	77.01	1000	980	970	-	-	914	914
B1	6.8	61,080	13,800	0.226	4.32	82.83	1000	995	980	960	940	895	895
B2	6.6	65,180	11,400	0.175	5.68	76.67	1000	990	960	-	-	920	930
C1	6.7	63,240	13,500	0.214	5.01	69.78	1000	995	970	952	930	890	890
C2	6.7	64,410	21,000	0.326	5.96	76.35	1000	995	970	946	926	886	885

Notes:
- Appearance of all samples - grey, soupy
- Obnoxious odor on all samples
- BOD and COD samples were diluted 100X
- Sludge was viewed under a 3D microscope at 10.5X power. It appeared to be bulky, filamentous and contained a high moisture content.
- A2 and B2 disturbed during six hour and eight hour readings for settleable solids.

Table 3
RAW SLUDGE BEDS D,E,F

Run 2 February 27, 1971

Sample	pH	COD mg/l	BOD mg/l	BOD/COD	Solids % Total	Solids % Vol	Settleable Solids (ml) 1 hr	2 hr	3 hr	4 hr	5 hr	6 hr	7 hr	8 hr	21 hr	22 hr	23 hr	24 hr
D1	6.97	42,700 39,000	13,200	0.323	3.90	67.9	982	965	949	920	903	890	878	868	827	826	826	826
D2	6.91	37,800 38,200	15,100	0.398	4.21	69.9	981	962	941	922	910	898	890	875	832	831	831	831
E1	6.90	33,700 35,800	17,700	0.509	3.61	68.7	983	970	947	931	912	896	881	867	812	810	810	810
E2	7.01	39,400 32,500	16,500	0.459	3.98	66.2	981	970	952	925	920	901	882	868	790	790	790	790
F1	6.99	42,700 34,700	16,100	0.416	3.87	69.7	980	967	945	933	915	904	893	881	830	830	830	830
F2	6.98	37,400 38,600	14,300	0.377	3.89	67.8	992	972	953	936	922	905	892	875	812	810	810	810

Notes: - Appearance of all samples - grey, soupy not as thick as Run 1.
- Odor obnoxious but not as bad as Run 1.
- Sludge return line only plugged 18 hours for this run; sludge is fresher than Run 1.

Table 4
RAW SLUDGE BEDS G,H,J

Run 3 March 19, 1971

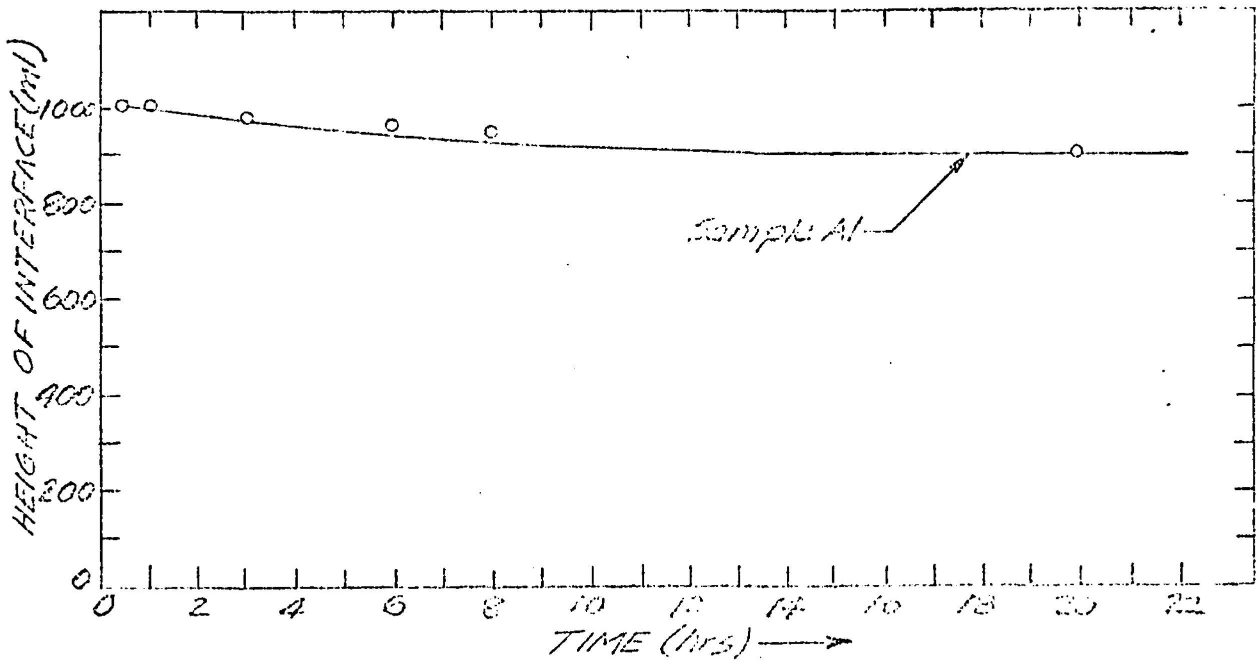
Sample	pH	BOD mg/l	COD mg/l	BOD/COD	Solids % Total	Solids % Vol	Settleable Solids (ml) 1/2 hr	1 hr	1-1/2 hr	2-1/2 hr	3-1/2 hr	4-1/2 hr	5-1/2 hr	19-1/2 hr	20-1/2 hr
G1	7.71	13,700	14,500	0.945	1.89	71.4	972	935	900	825	750	700	670	550	550
G2	7.65	16,500	16,800	0.981	1.92	70.6	985	945	895	705	620	585	550	455	455
H1	7.68	17,600	23,700	0.742	1.94	72.2	982	950	910	830	750	690	655	540	540
H2	7.65	15,700	17,600	0.892	2.12	69.4	965	945	815	660	565	515	490	410	410
J1	7.68	19,500	21,000	0.929	1.87	74.6	975	935	890	805	725	670	640	540	540
J2	7.63	14,500	15,700	0.923	1.91	71.7	980	920	810	795	590	540	515	445	445

Notes: Appearance of all samples - grey, soupy, more pourable than earlier runs.
Color is oily, not obnoxious.

Table 4-A
SUPERNATANT ANALYSIS FROM SETTLEABILITY TEST

Sample	Suspended Solids mg/l	BOD mg/l
G1	500	760
G2	300	98
H1	700	347
H2	400	149
J1	100	494
J2	200	345

Figure No 12 Settleability of Raw Sludge - Run 1



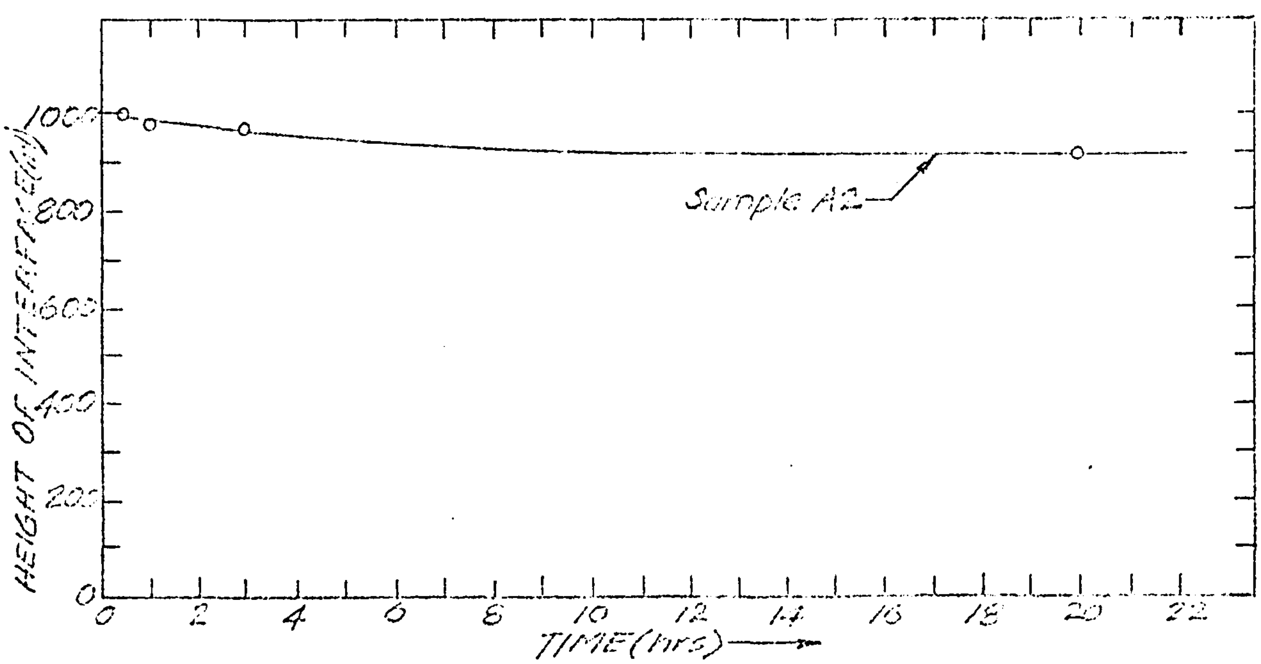
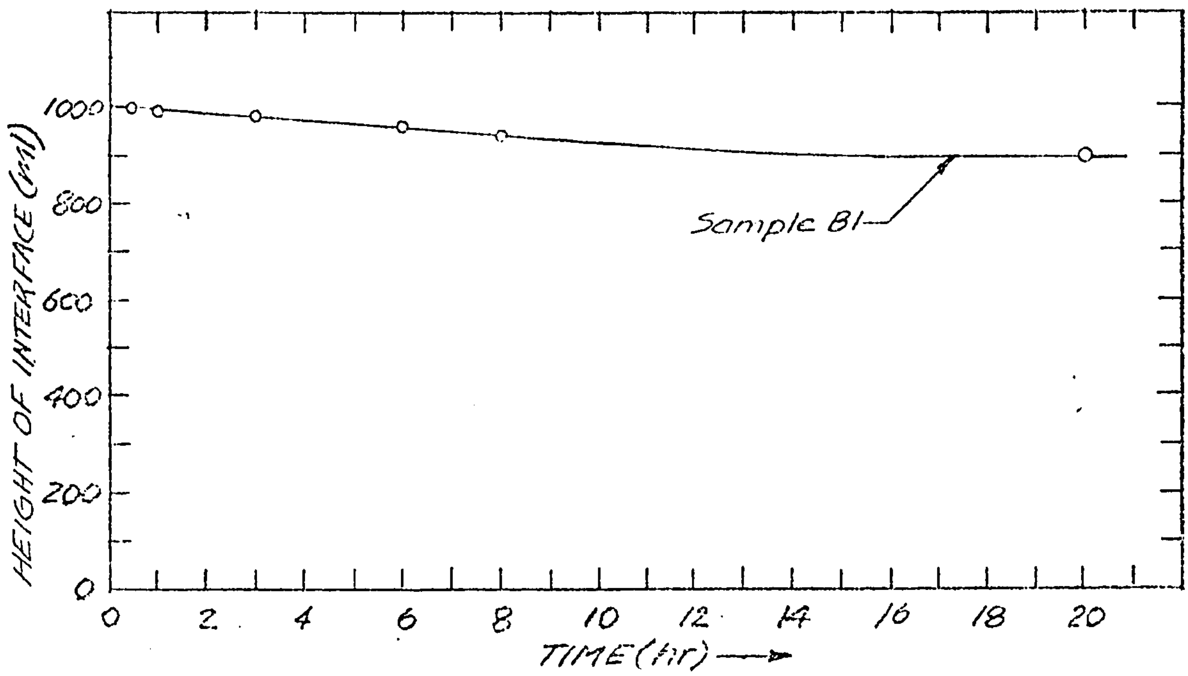


Figure No. 13 Settleability of Raw Sludge—Run I



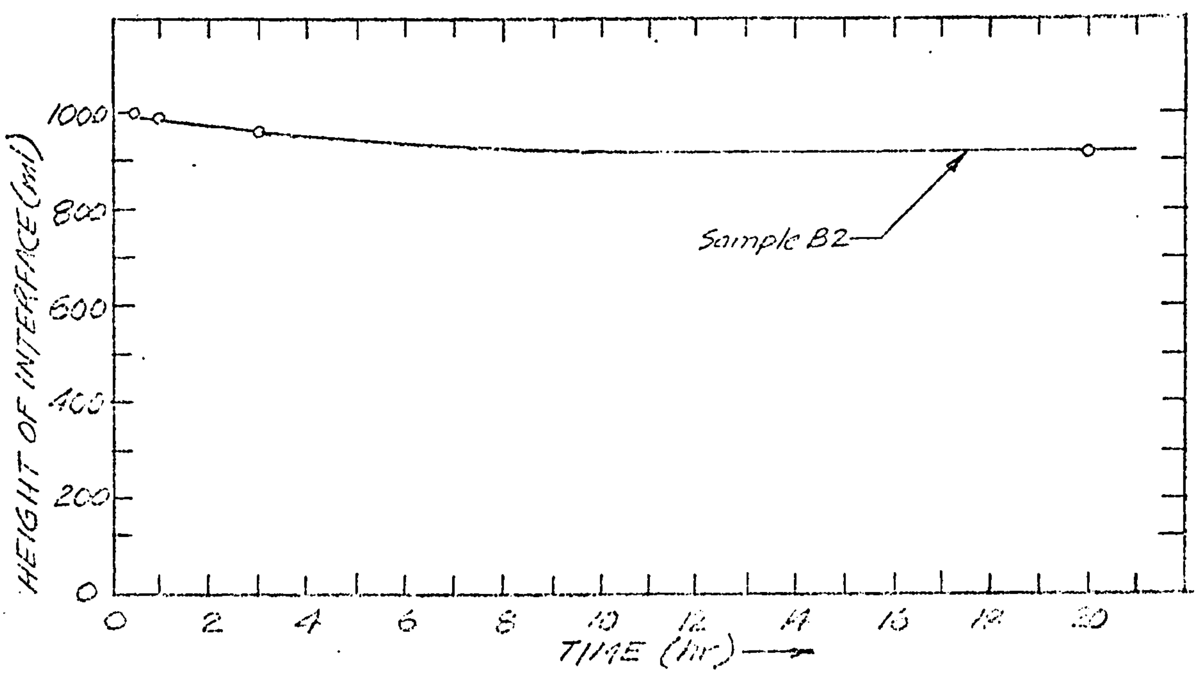
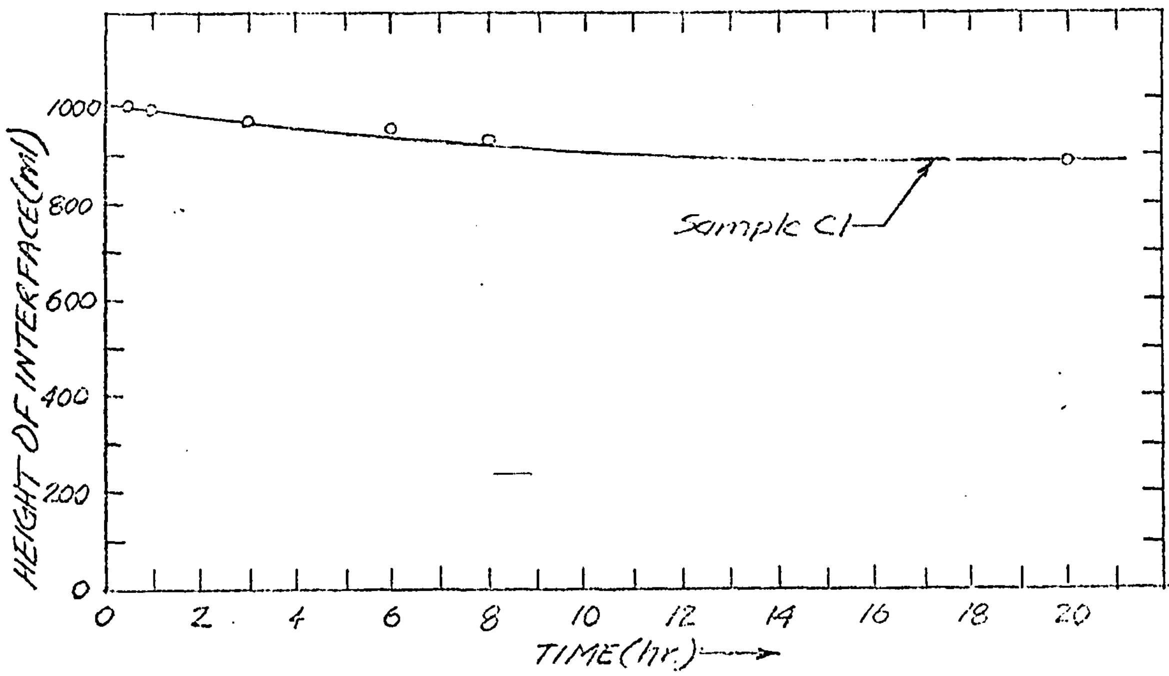


Figure No. 14 Settleability of Raw Sludge - Run 1



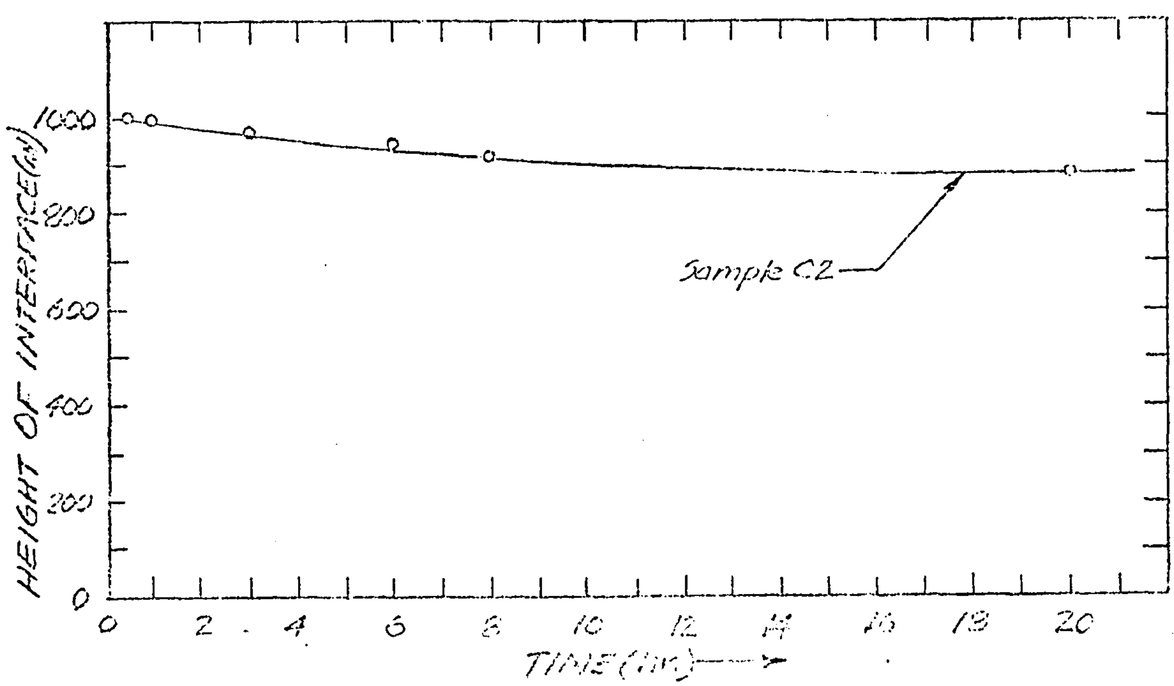
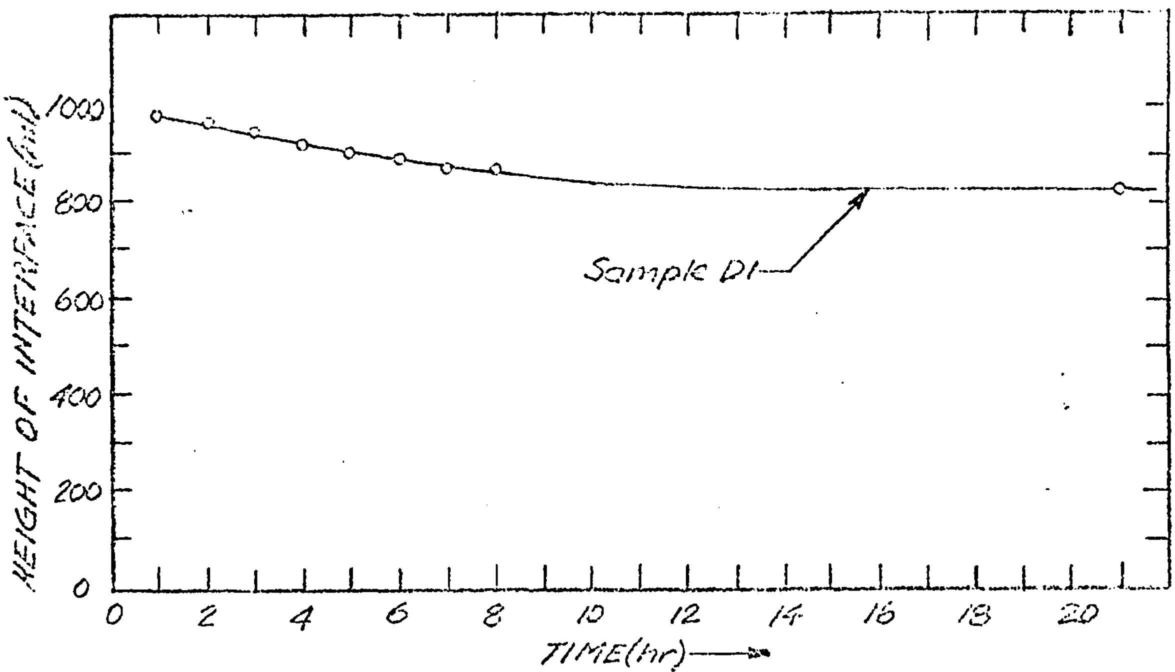


Figure No. 15 Settleability of Raw Sludge-Run 2



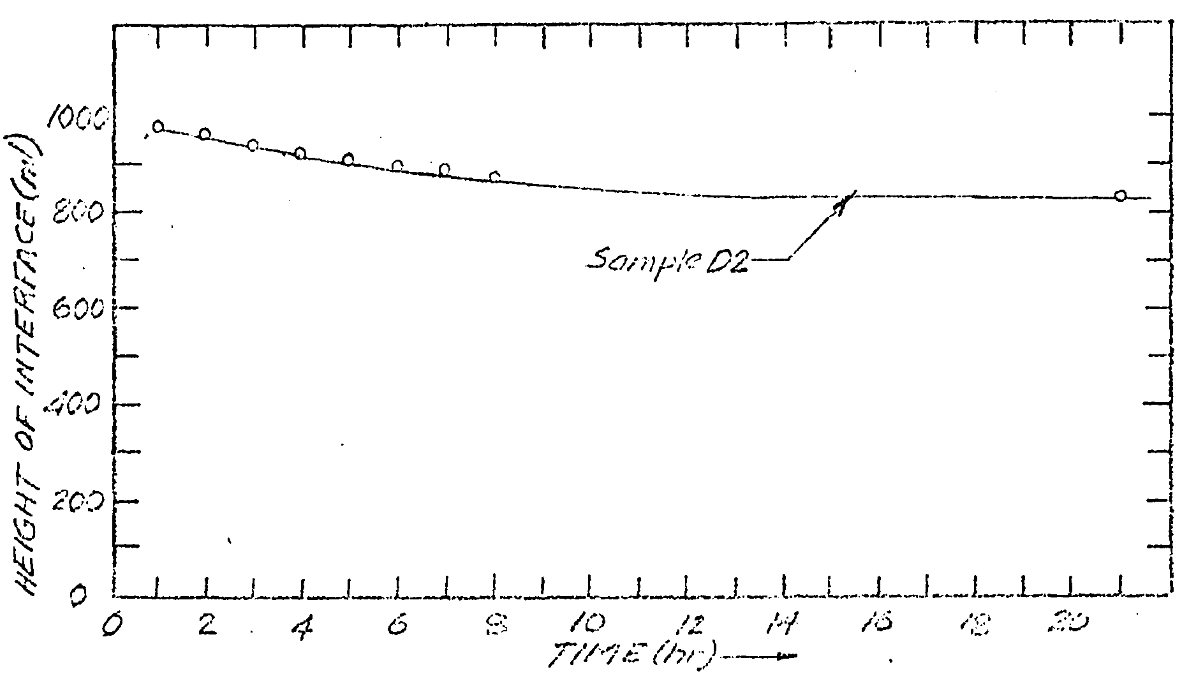
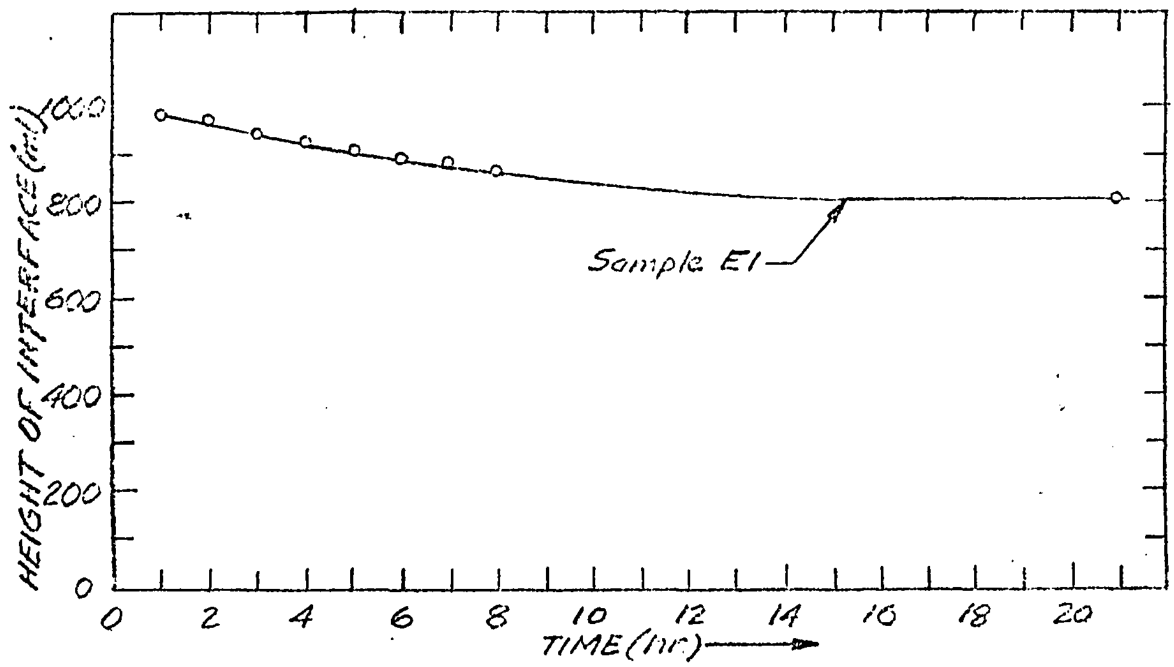


Figure No. 16 Settleability of Raw Sludge - Run 2



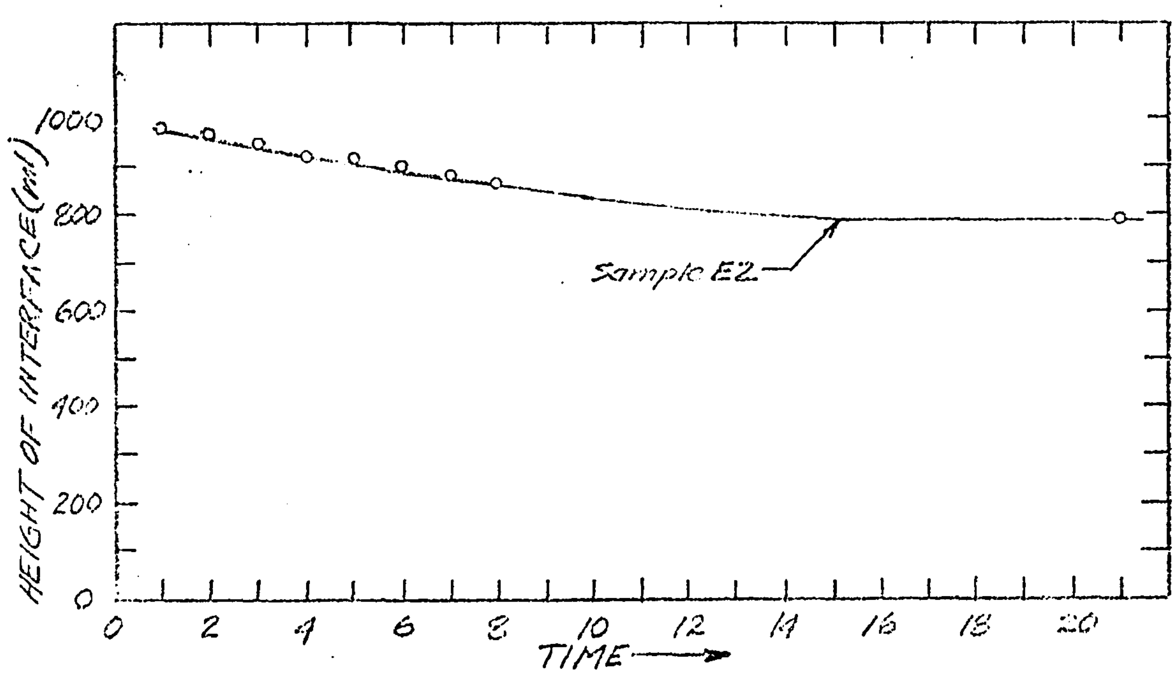
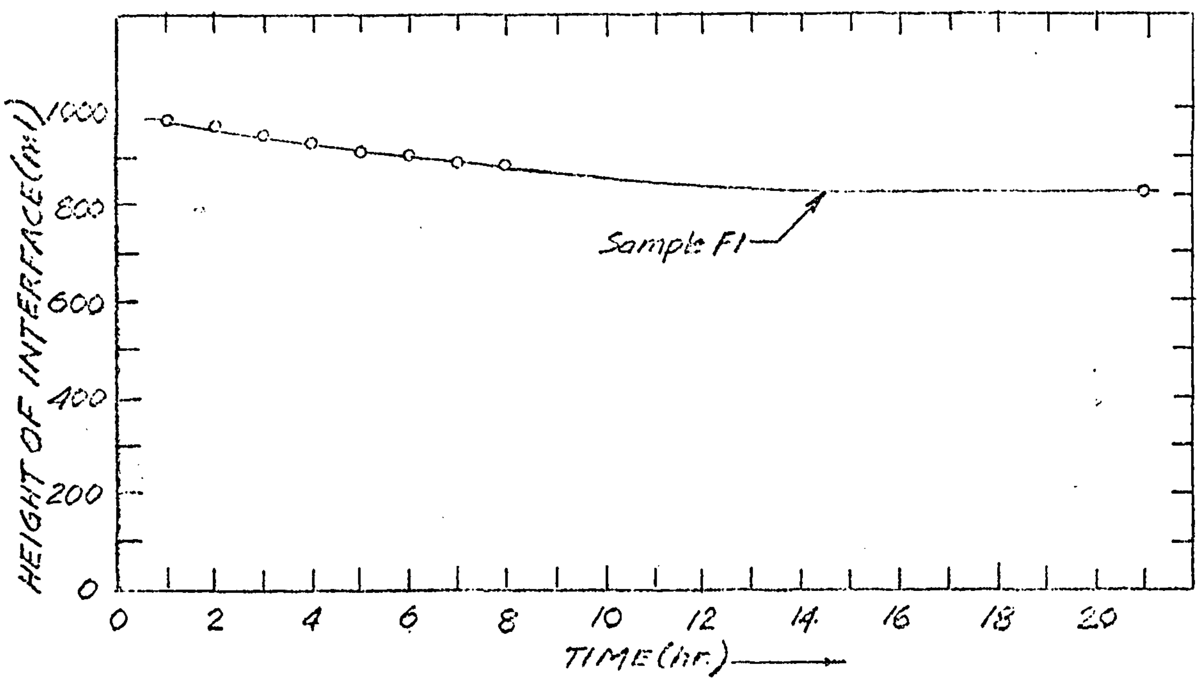


Figure No. 17 Settleability of Raw Sludge - Run 2



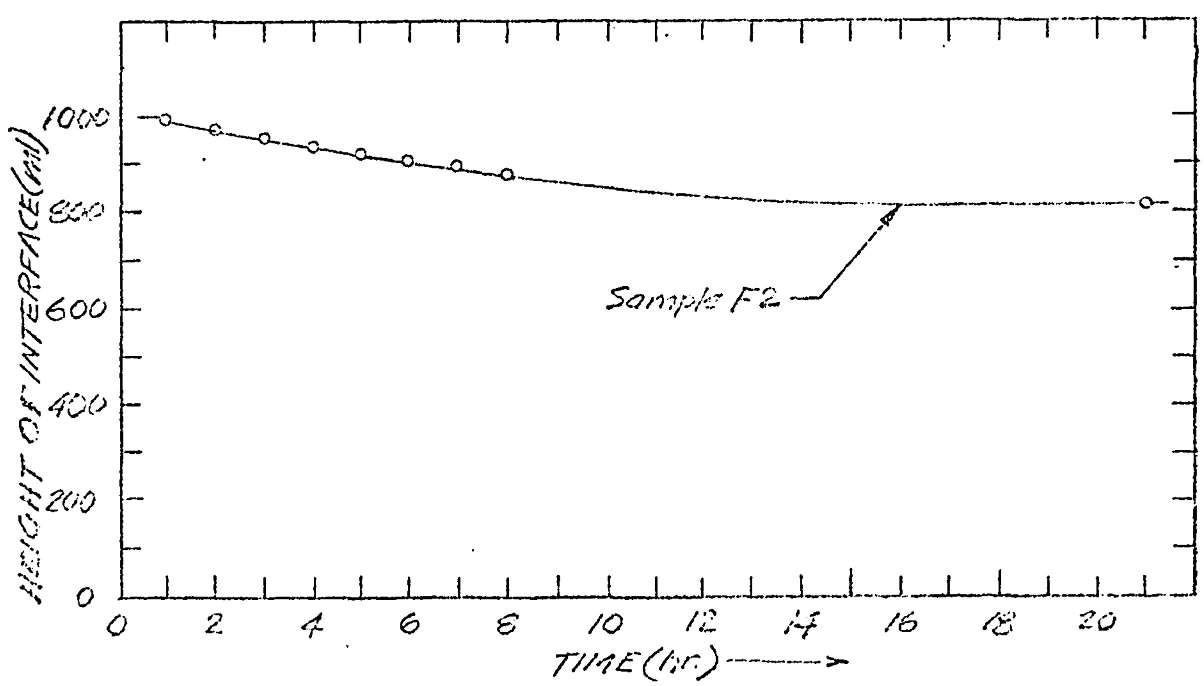


Figure No. 18 Settleability of Raw Sludge - Run 3

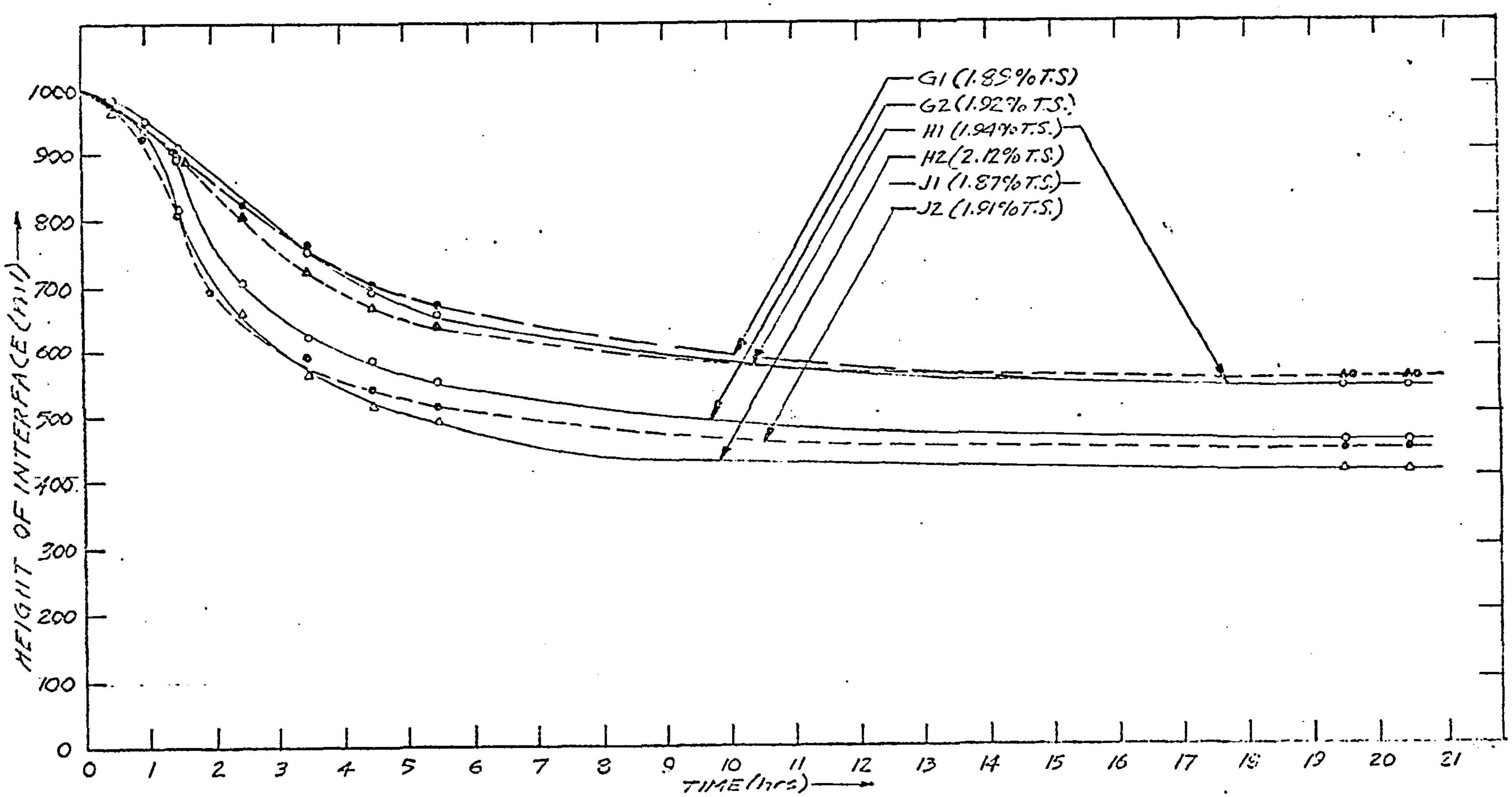
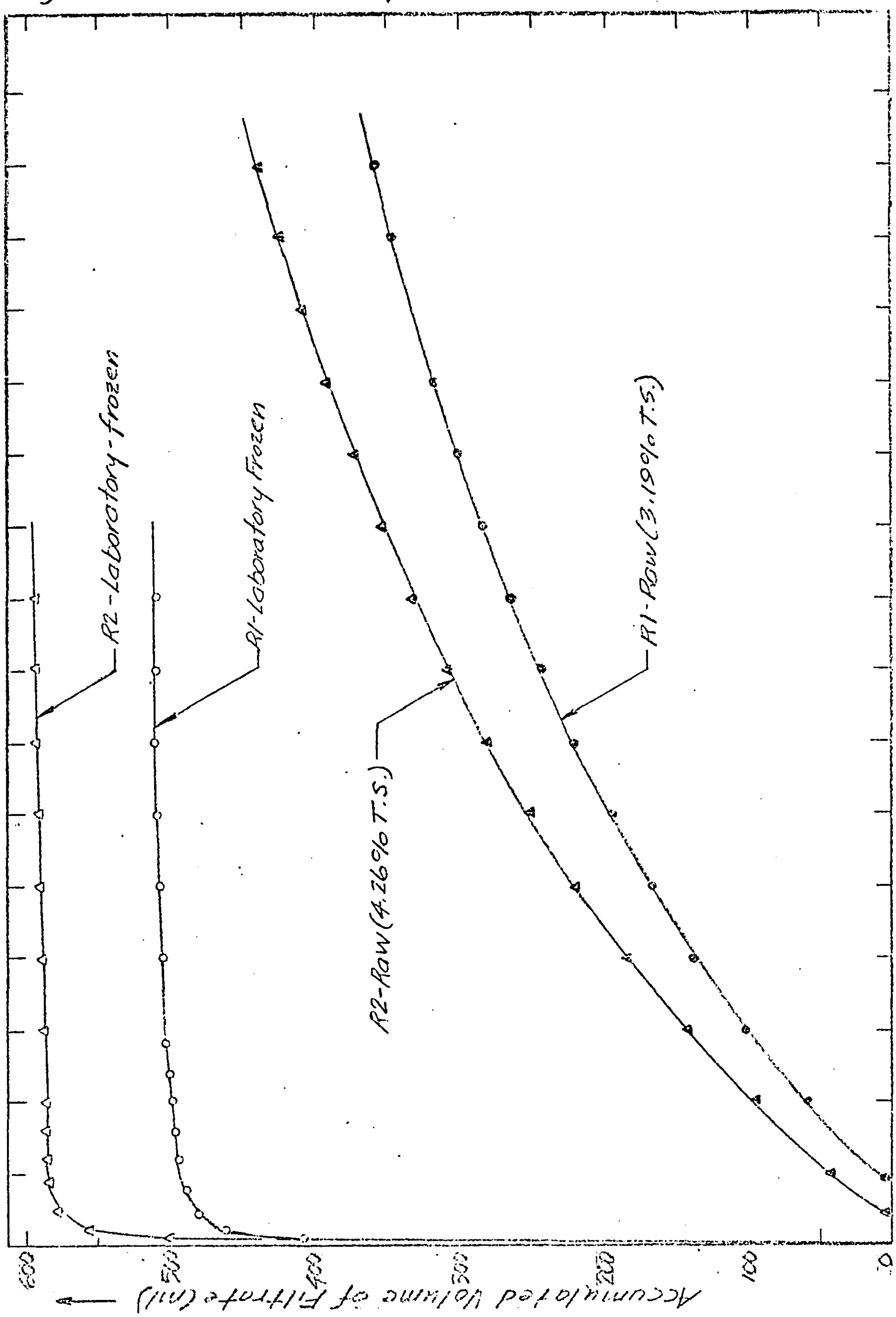


Figure No.19 Drainability - Lab-Frozen vs. Raw Sludge



B. Frozen Sludge Core Data

The physical and chemical analyses for the core samples and their sections are incorporated into Table 28 in the Appendix. The depth of the core section is denoted by the numbers following the core sample number; for example, F9-12 refers to a section of core F taken between nine and 12 inches from the sludge bed surface. The six-inch nominal depth cores are simply divided into thirds and denoted "T", "M", "B" to signify top, middle and bottom, respectively. The three phases analyzed are clearly marked in the table. Comments on unique physical features are included as footnotes to the table. The core analyses results are graphically represented in Figures 60A to 60Q. All figures are included in the Appendix except Figure 20, a representation of the results for core F, from an 18-inch (nominal) bed. Figure 37 is a photograph of this core. Figures 36 to 48, inclusive, are photographs of some cores and core sections in the frozen and thawed state.

C. Field Data

All tabulated sludge temperature data are included in Tables 17, 18 and 19, embracing data from the first, second and third run, respectively. These tables contain average air temperatures during the first run, the second run, the third run and the thawing and drying period. The temperature data is contained exclusively in the Appendix. Graphical representatives of average daily sludge temperature and air temperature versus time are incorporated into this chapter as Figures 21, 22 and 23 for the first run; Figures 24, 25 and 26 for the second run and Figures 27, 28 and 29 for the third run. Freezing and thawing rates and times can be deduced from these curves.

Figure No. 20 - Core Analyses - Sample F

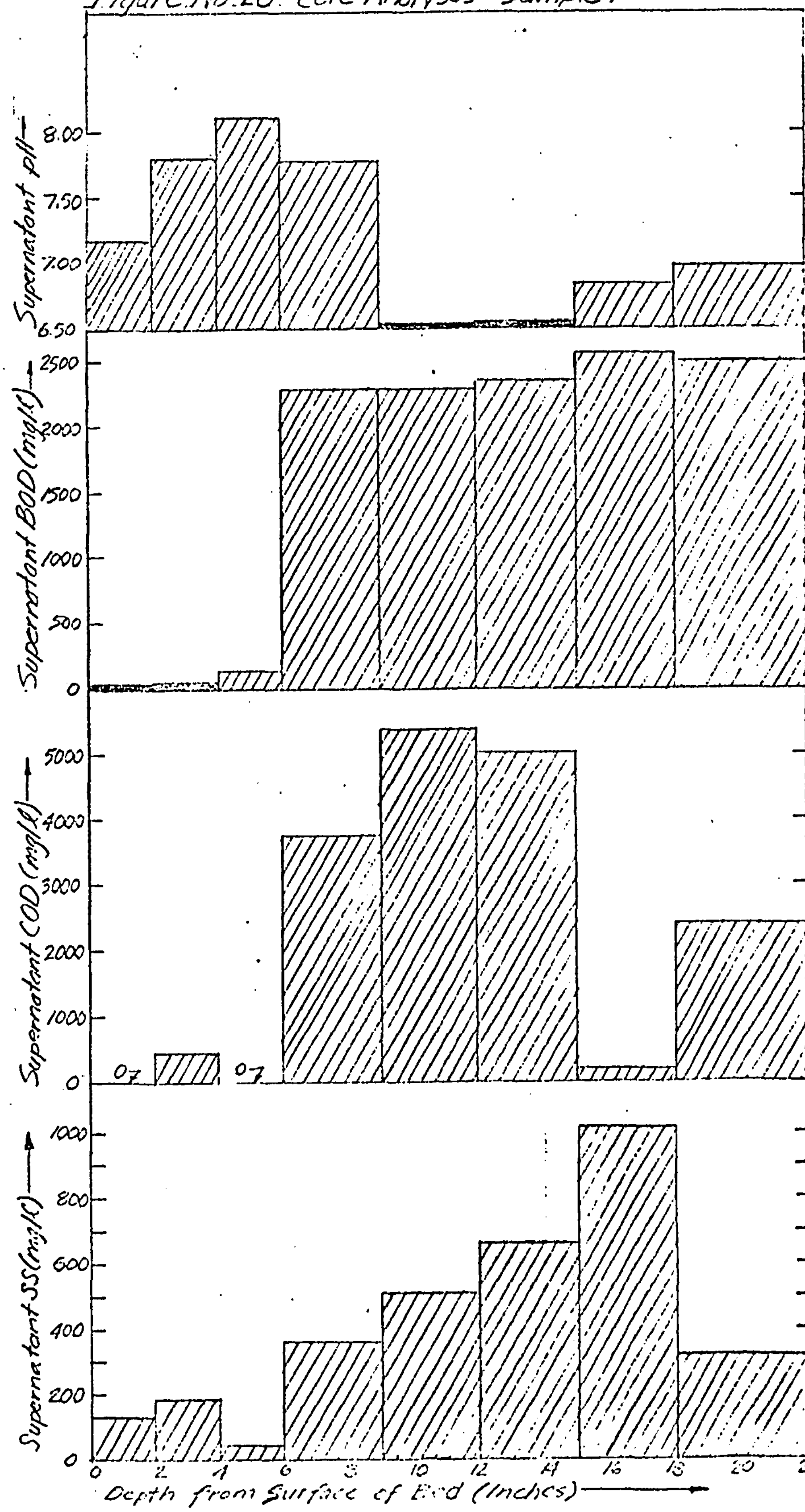


Table 20, included in the Appendix, illustrates the results of the afternoon relative humidities, weather conditions and air temperatures observed during the thaw. A graphical representation of these data is presented in Figure 30 in this chapter. These data were used to estimate evaporation rates during the thaw.

The results of some 130 samples collected from the beds during the period April 24 to June 2 and analyzed for total solids, total volatile solids and physical characteristics are incorporated in Tables 21A through 21X in the Appendix. Table 5 and Figure 31 condense these data and form part of this chapter.

The results of analyses performed on samples of liquid collected from the top of the sludge beds during late April are found in Table 6. Tables 8 and 11 describe the results of analyses conducted on thawed ice samples collected from the top 1-1/2 inches of Beds C, F, G, H and J during initial stages of the thaw.

The qualitative field thaw data were condensed as much as possible from field notes and are included in Appendix III. These data include daily sludge depths, sludge condition, extent of thaw and site conditions. A sample sheet is included for reference in this chapter as Table 9. From the field thaw data Table 22 was constructed and is included in the Appendix. A graphical representation thereof is incorporated in this chapter in Figures 32, 33 and 34.

Computations pertaining to sludge depths as related to solids concentrations and degree-hours required for complete freezing and thawing are embodied in Table 10 and Table 11, respectively.

Table 12 and Table 13 contain the nutrient data and interpretation of these data. Calculations pertaining to evaporation during the thaw

Figure No. 21 Average Daily Sludge Temperatures - Run 1 - Bed A

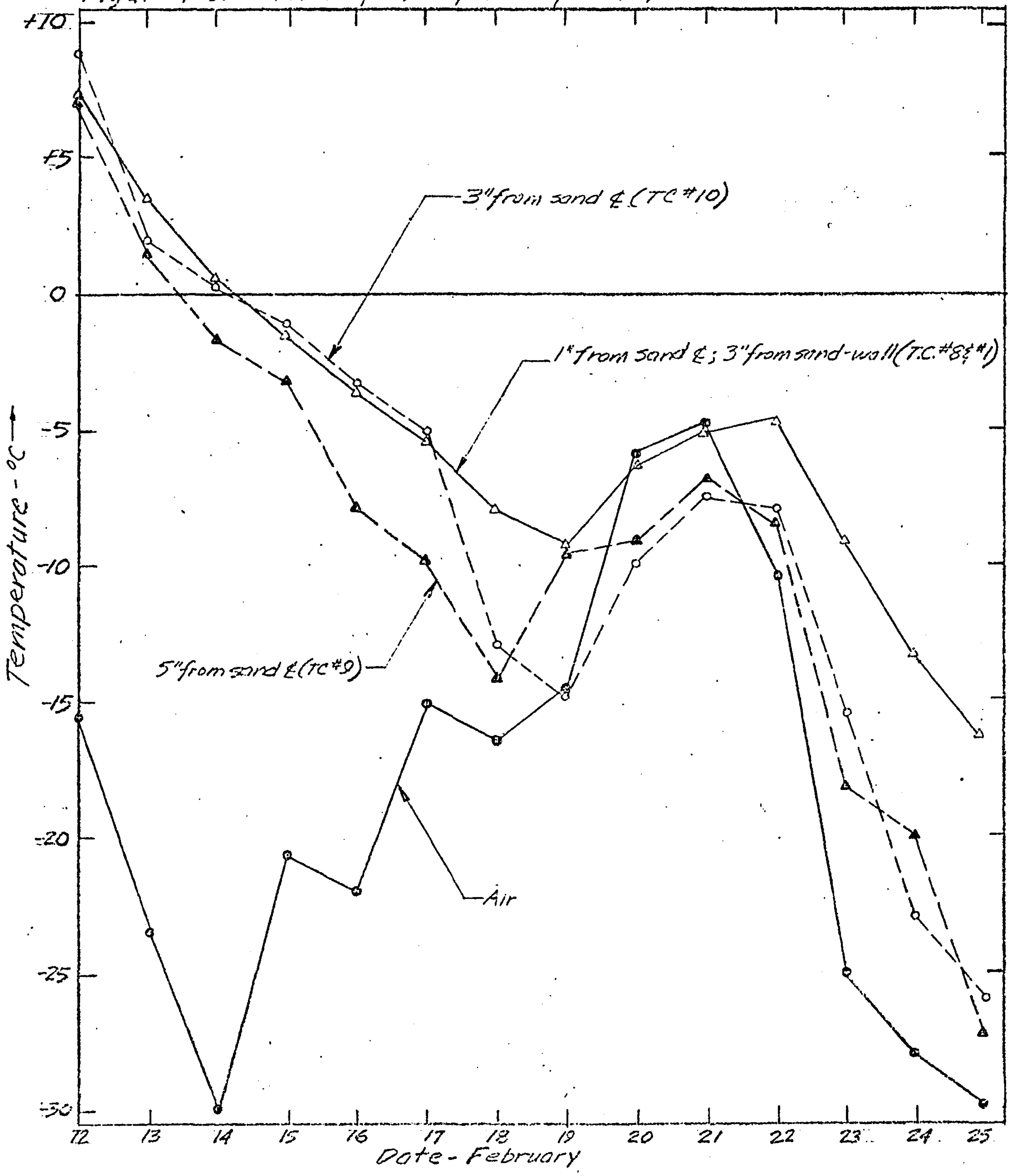


Figure No.22 Average Daily Sludge Temperatures-Run 1 - Bed B

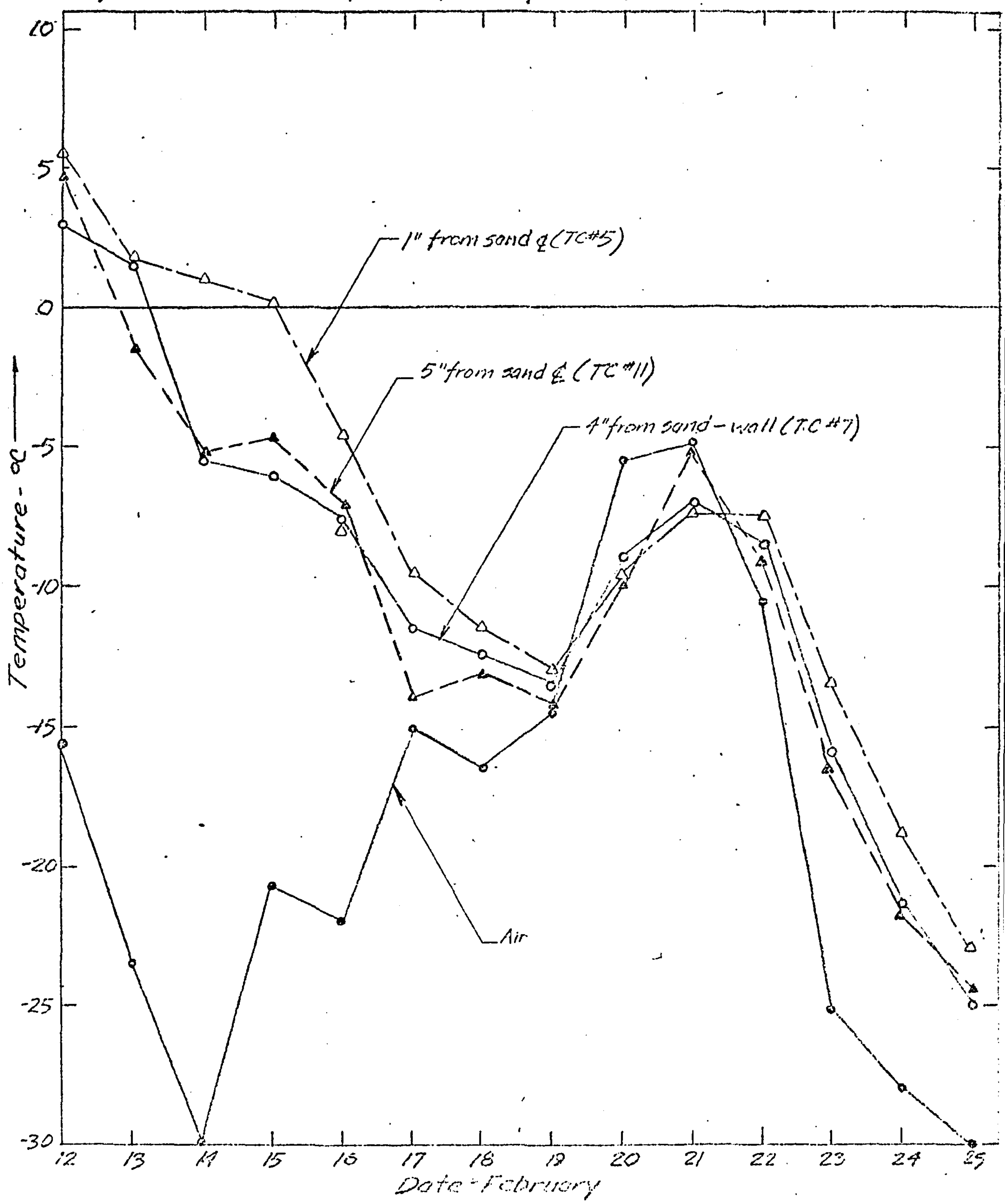


Figure No. 23 Average Daily Sludge Temperatures-Run 1-Bed C

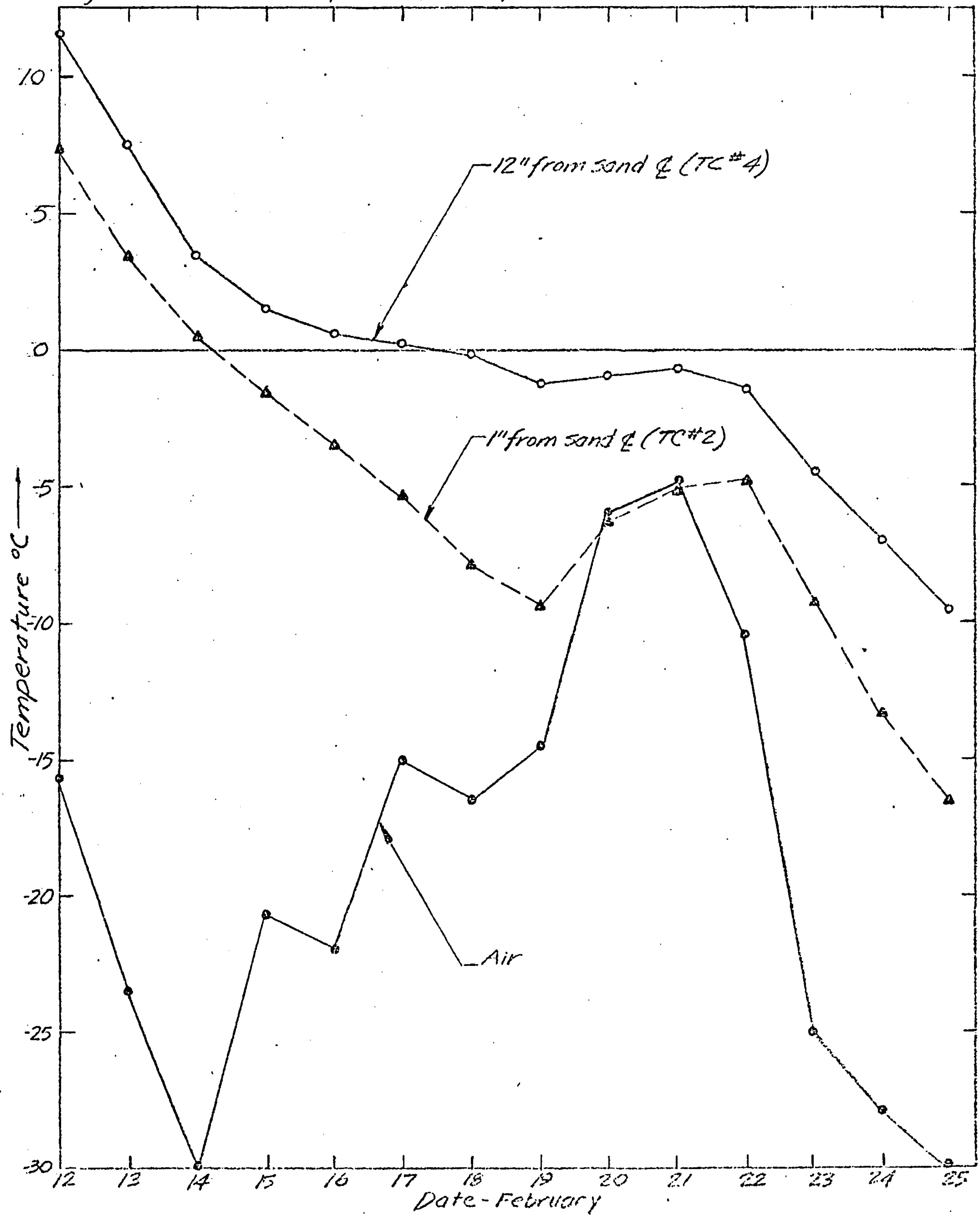


Figure No. 24 Average Daily Sludge Temperatures Run 2 – Bed D

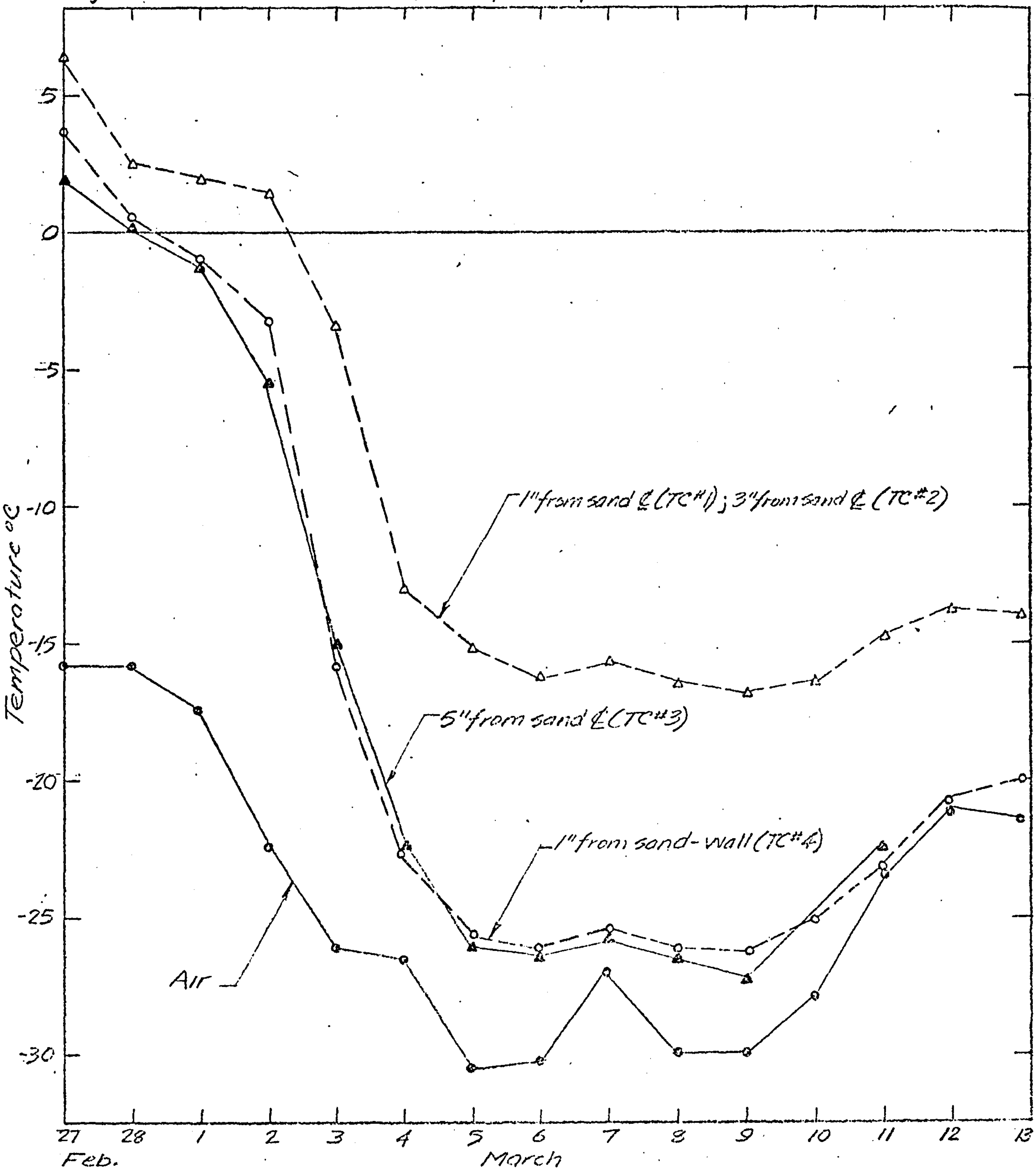


Figure No. 25 Average Daily Sludge Temperatures - Run 2 - Bed E

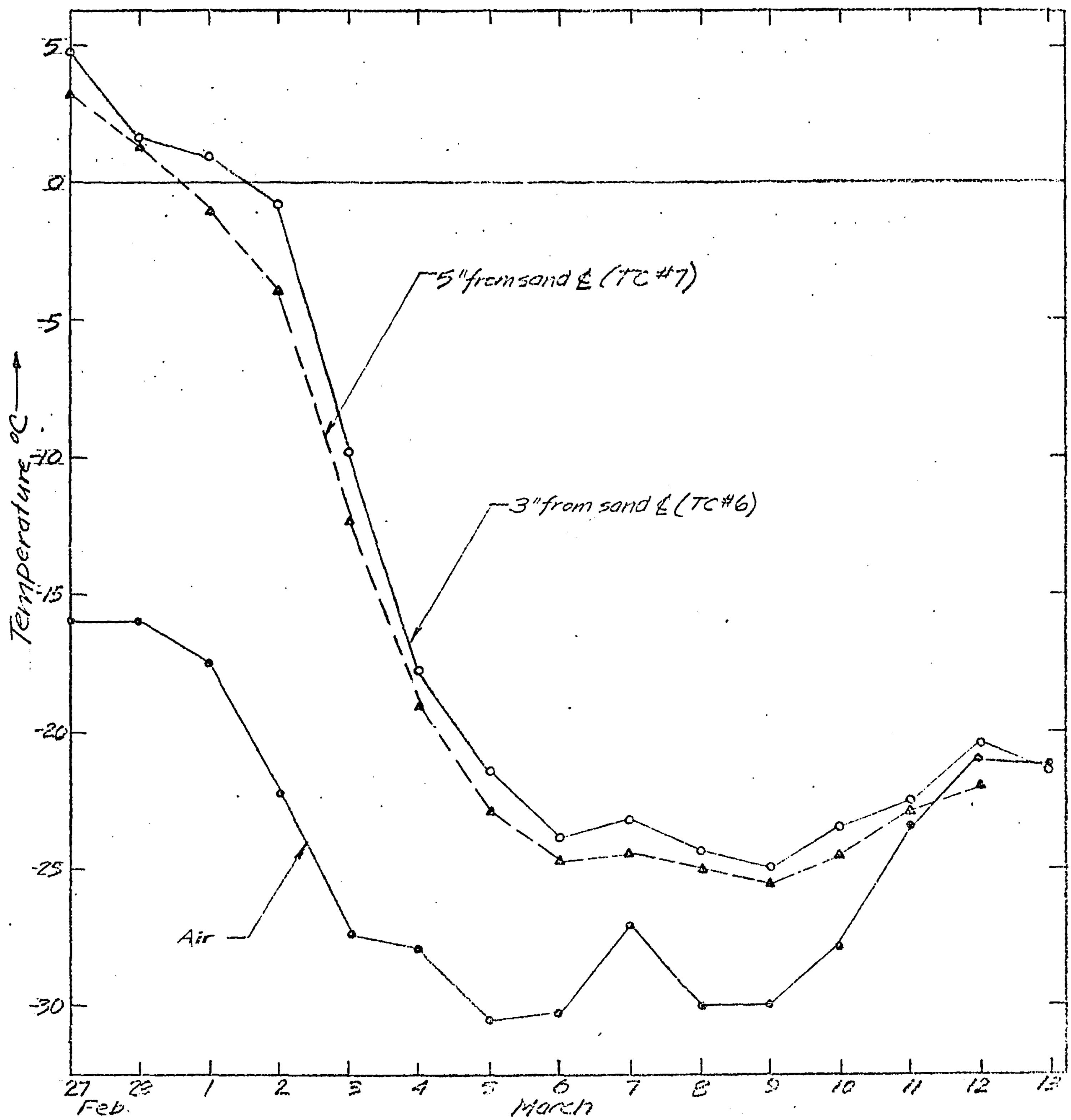
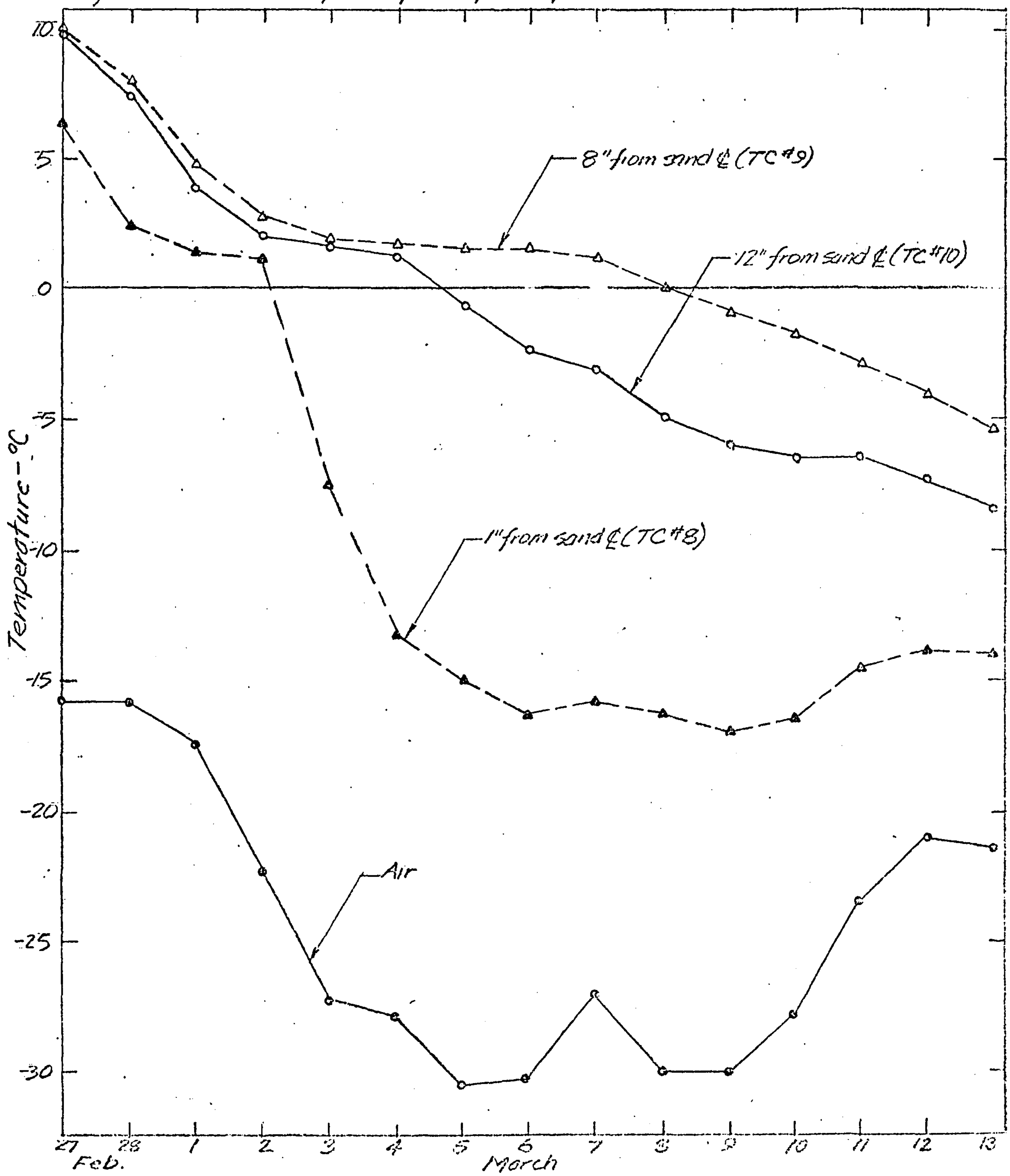


Figure No 26 Average Daily Sludge Temperature - Run 2 - Bed F



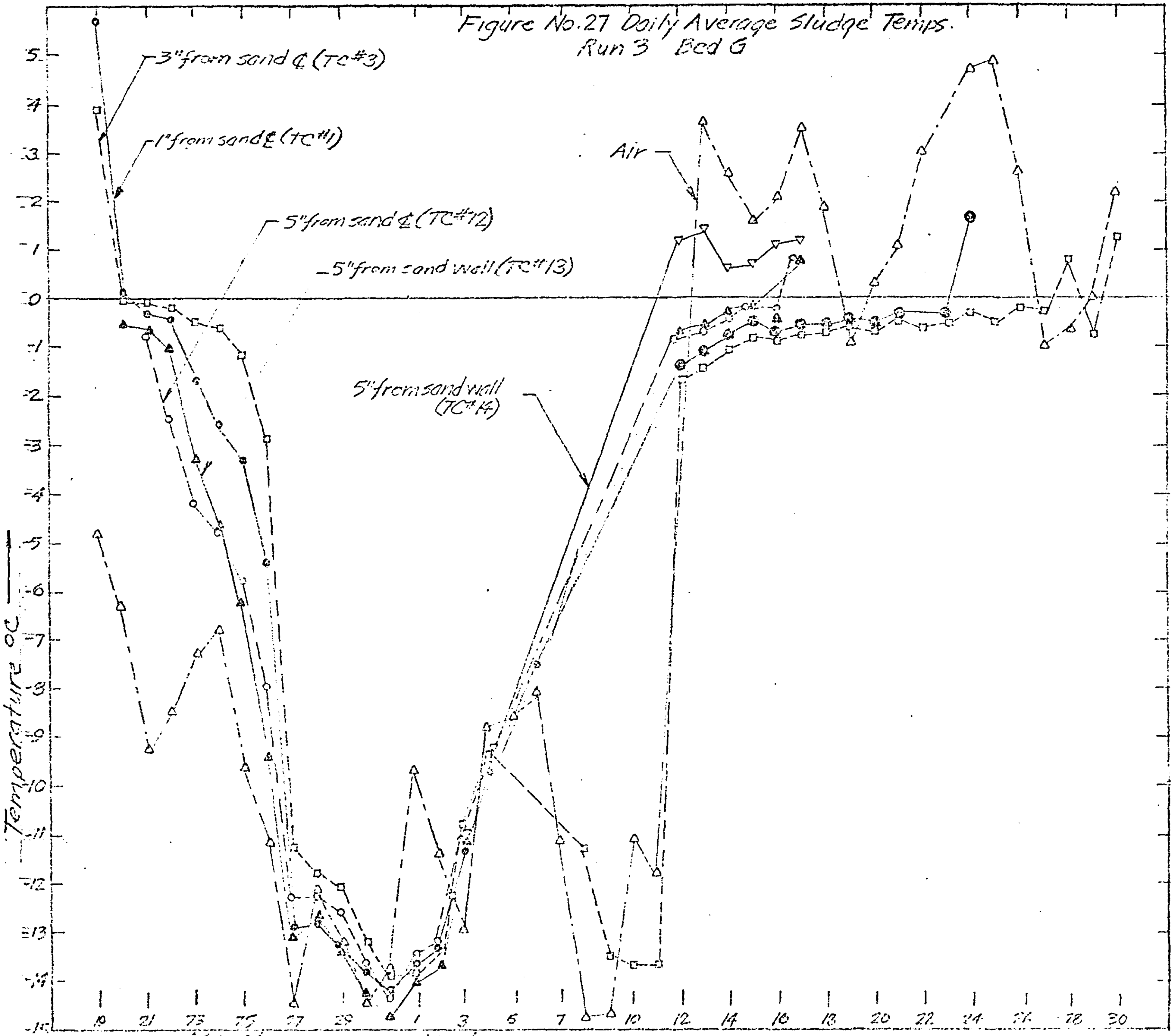


Figure No. 27 Daily Average Sludge Temps.
Run 3 Bed G
3" from sand ℄ (TC#3)
1" from sand ℄ (TC#1)
5" from sand ℄ (TC#12)
5" from sand wall (TC#13)
5" from sand wall (TC#14)
Air
Temperature °C
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
19
21
23
25
27
29
1
3
5
7
10
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14
16
18
20
22
24
26
28
30

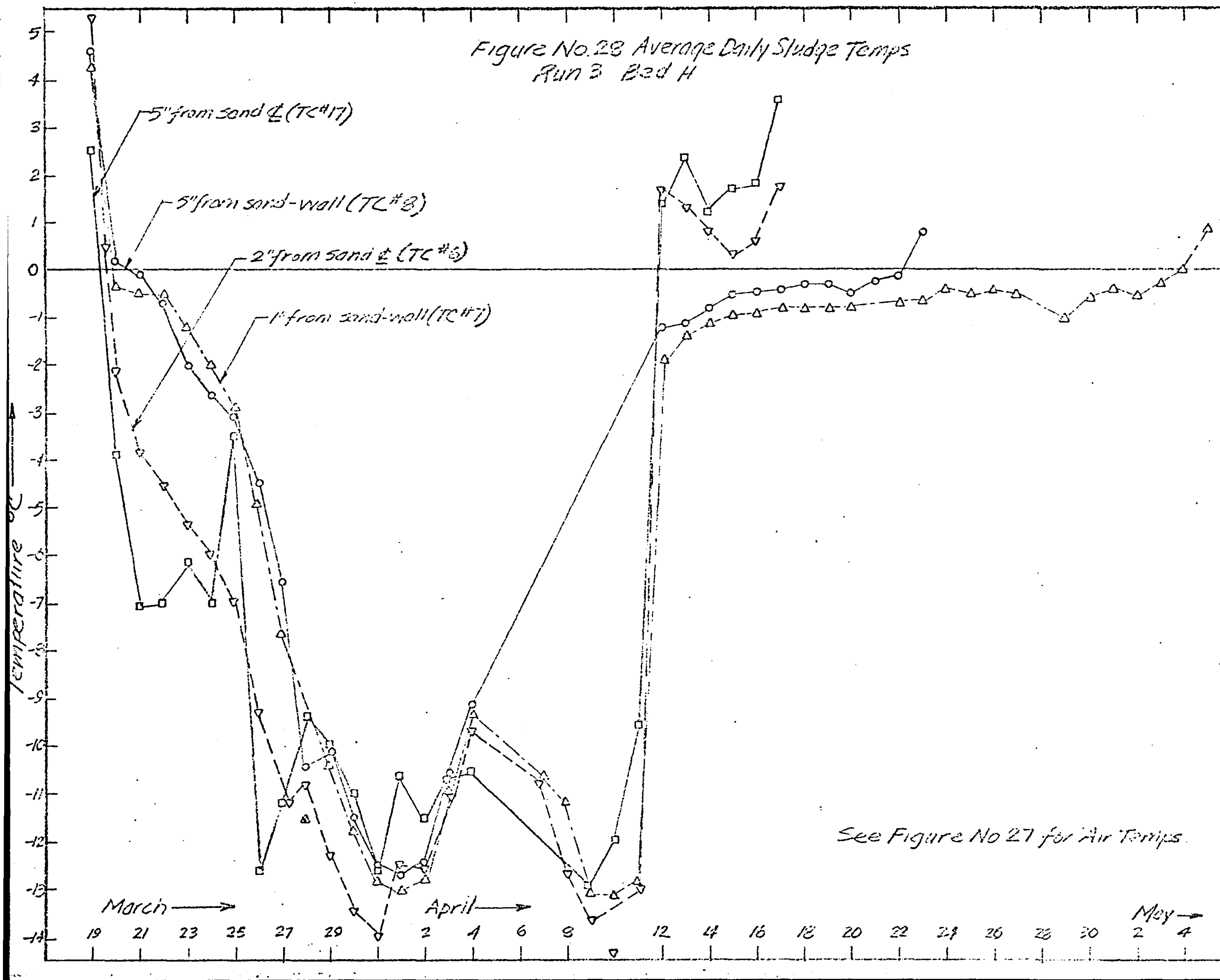


Figure No. 28 Average Daily Sludge Temps
Run 3 Bed H
5" from sand ℄ (TC#17)
5" from sand-wall (TC#8)
2" from sand ℄ (TC#6)
1" from sand-wall (TC#7)
Temperature °C
See Figure No 27 for Air Temps
March
April
May
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
19
21
23
25
27
29
2
4
6
8
12
14
16
18
20
22
24
26
28
30
2
4

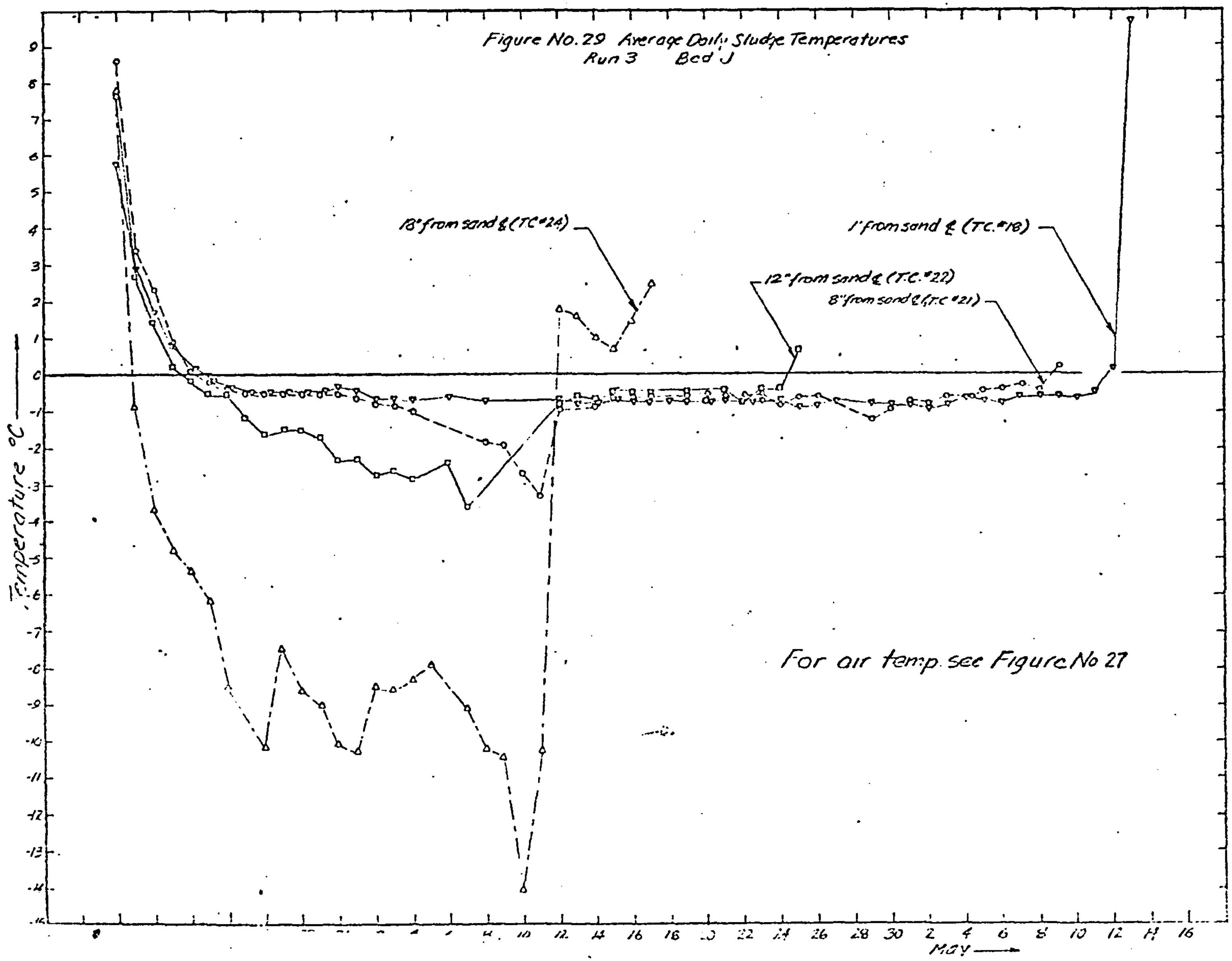


Figure No. 29 Average Daily Sludge Temperatures
Run 3 Bed J
18" from sand ℄ (T.C.#24)
1" from sand ℄ (T.C.#18)
12" from sand ℄ (T.C.#22)
8" from sand ℄ (T.C.#21)
For air temp. see Figure No 27
Temperature °C
May

Figure No. 30 - Relative Humidities during Thaw Period

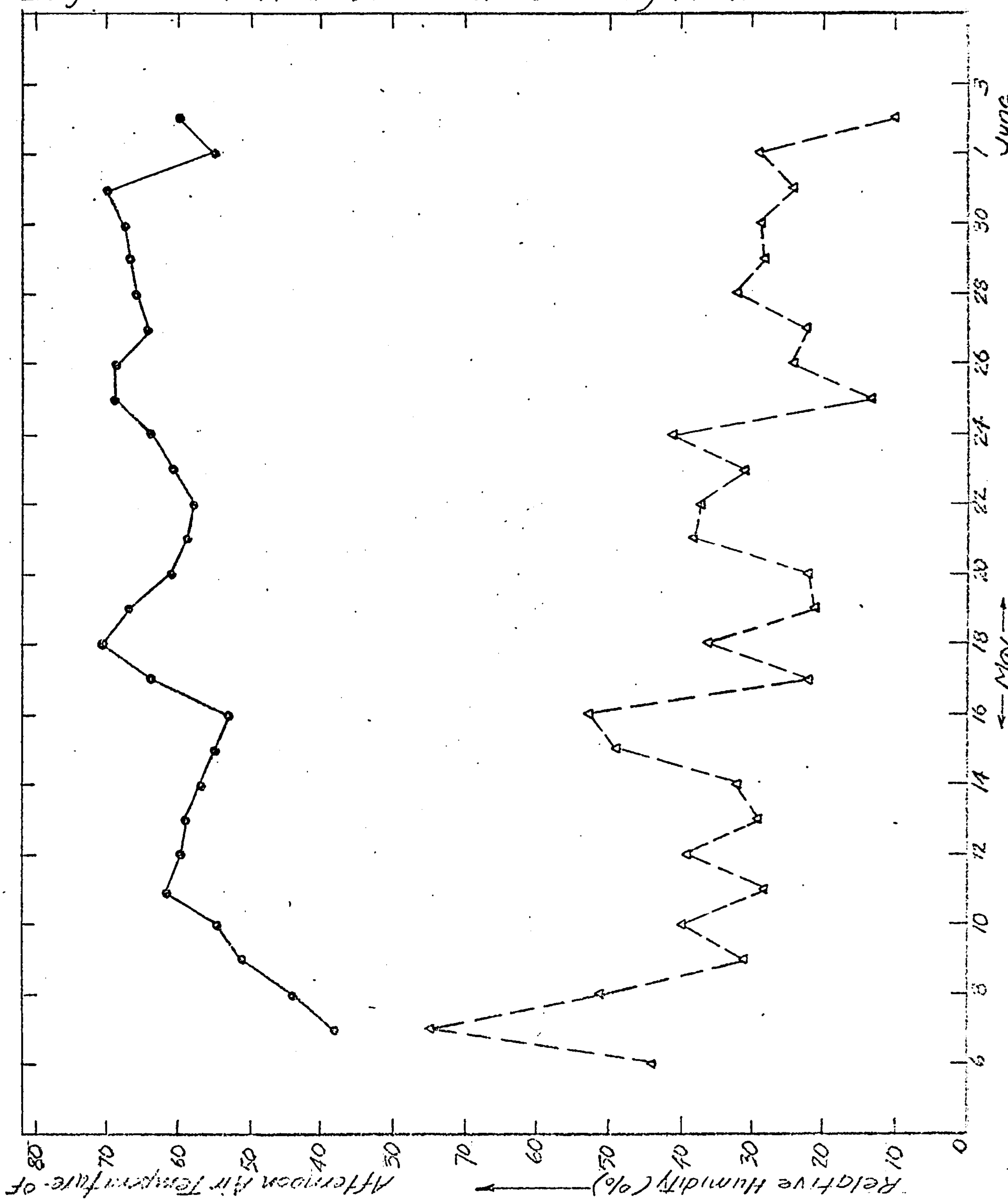


Table 5
SLUDGE SOLIDS CONTENT (% TS)

Sampling Date	SAMPLE A	B	C	D	E	F	G	H	J
April 24	-	-	-	-	-	-	34.7%	32.8%	-
April 25	-	-	-	19.35	19.45	-	20.25	16.50	-
April 26	-	-	-	20.9	20.5	-	20.6	18.4	-
April 28	-	-	-	41.7	34.9	-	23.3	22.4	-
May 1	-	-	-	64.1	49.8	-	21.6	25.6	-
May 3	13.9	19.4	17.8	22.0	28.8	11.8	23.7	24.8	15.7
May 5	26.0	24.0	18.3	25.4	26.3	16.6	21.2	28.4	12.1
May 7	21.2	25.4	16.8	25.2	25.8	18.3	25.1	34.5	13.2
May 10	23.2	22.5	16.9	34.5	31.7	19.0	31.1	40.6	15.1
May 12	49.1	38.4	32.5	49.3	48.7	34.6	40.4	69.1	29.9
May 13	24.8	23.8	19.6	50.8	33.4	20.1	47.6	57.2	24.6
May 15	34.3	37.9	19.5	36.4	31.4	22.2	64.0	57.8	26.2
May 18	28.5	36.9	19.5	37.9	32.2	24.7	69.1	78.9	25.3
May 20	-	-	31.7	-	-	25.2	-	-	25.7
May 22	-	-	29.1	-	-	29.6	-	-	-
May 24	42.6	46.7	25.4	42.9	49.1	26.1	93.1	84.6	34.7
May 26	-	-	31.4	-	-	33.5	-	-	39.5
May 28	-	-	29.2	-	-	39.4	-	-	40.6
May 30	59.1	48.3	31.6	43.5	60.9	43.5	91.3	86.3	39.7
June 2	-	-	35.5	-	-	36.8	-	-	43.7
June 5	-	-	39.4	-	-	46.7	-	-	56.7
June 9	-	-	39.1	73.7	-	54.9	-	-	47.3

Figure No. 31 - Solids Content of Field Samples from Beds

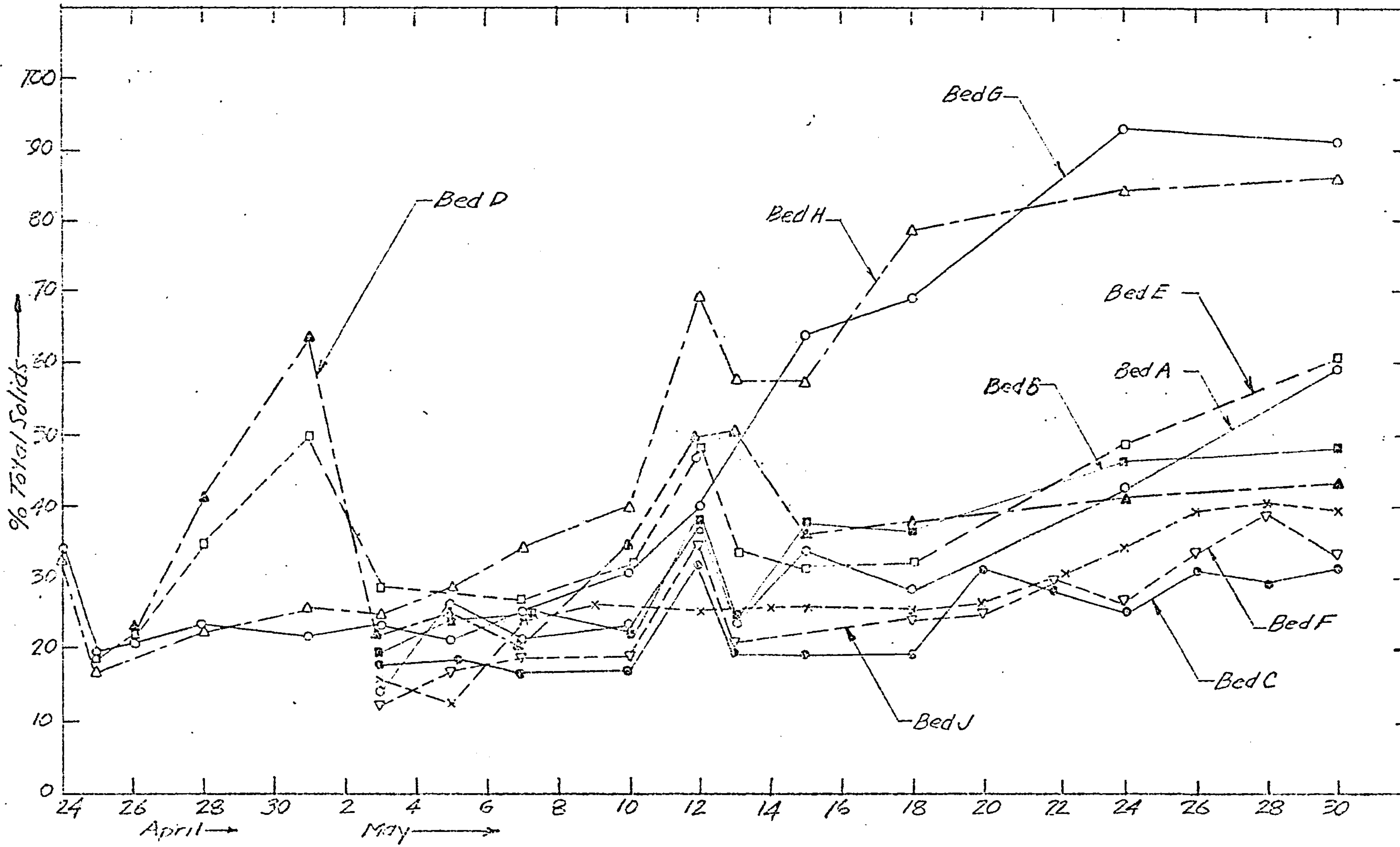


Table 6
SAMPLES COLLECTED OFF TOP OF SLUDGE ICE

Sample	pH	COD mg/l	BOD mg/l	BOD/COD	S.S. mg/l	V.S.S. mg/l	T.S. mg/l	T.V.S. mg/l	Diss. Solids mg/l (Calc.)
Collected April 17, 1971									
H	8.70	573	≥516	≥0.90	135	70	1417	526	1282
J	7.79	776	≥516	≥0.665	225	105	1568	-	1343
Collected April 20, 1971									
H	-	-	-	-	845	480	2730	780	1885
J	-	-	-	-	310	165	1290	761	980
Collected April 23, 1971									
H	7.65	914	470	0.514	1530	846	3390	1798	1860
J	7.78	560	235	0.419	662	406	1307	662	0

Notes:
1. None of samples exhibited odor.
2. Sample H possibly has grit inclusion on occasion.
3. Some of solids are likely due to disturbance of underlying solids during core sampling.
4. The clarity of these samples was excellent and resembled that of water.

Table 7
SAMPLES OF ICE COLLECTED FROM TOP 1-1/2" OF BEDS F,G,H

Sample	pH	BOD mg/l	COD mg/l	T.S. mg/l	T.V.S. mg/l	S.S. mg/l	V.S.S. mg/l	Diss. Solids mg/l (Calc.)
Sampled April 22, 1971								
F	-	-	-	590	334	554	286	36
G	-	-	-	344	133	158	80	186
H	-	-	-	567	174	356	144	211
Sampled April 23, 1971								
F	7.81	-	-	414	320	148	80	266
G	7.58	-	-	844	834	58	20	786
H	7.65	-	-	268	230	112	56	156

Notes: 1. F is the only sample exhibiting odor.
2. G and H likely have grit inclusions.

Table 8
SAMPLES OF ICE COLLECTED FROM TOP 1-1/2" OF BEDS C,F,J APRIL 29, 1971

Sample	pH	BOD mg/l	COD mg/l	$\frac{BOD}{COD}$	S.S. mg/l	V.S.S. mg/l	T.S. mg/l	T.V.S. mg/l	Diss. Solids mg/l (Calc.)
C	7.68	19,500	53,500	0.365	N.D.	-	33,127	31,846	N.D.
F	7.94	112	284	0.395	332	134	765	340	433
J	7.05	48	150	0.320	248	82	239	151	0

Notes:

1. N.D. = Not Done
2. Sample C too thick to perform suspended solids
3. Sample C diluted 50X to do BOD, COD
4. Sample C showed a different consistency than raw sludge; there was little cohesion, the solid particles were dispersed and the solids separated very quickly from the liquid.
5. BOD's were done using no seed.
6. C had an odor but not as obnoxious as raw sludge.
   F had a slight odor.
   J had no odor.
7. Grit-like particles observed in bottom of samples C and F.

Figure No. 32 Sludge Depth versus Time

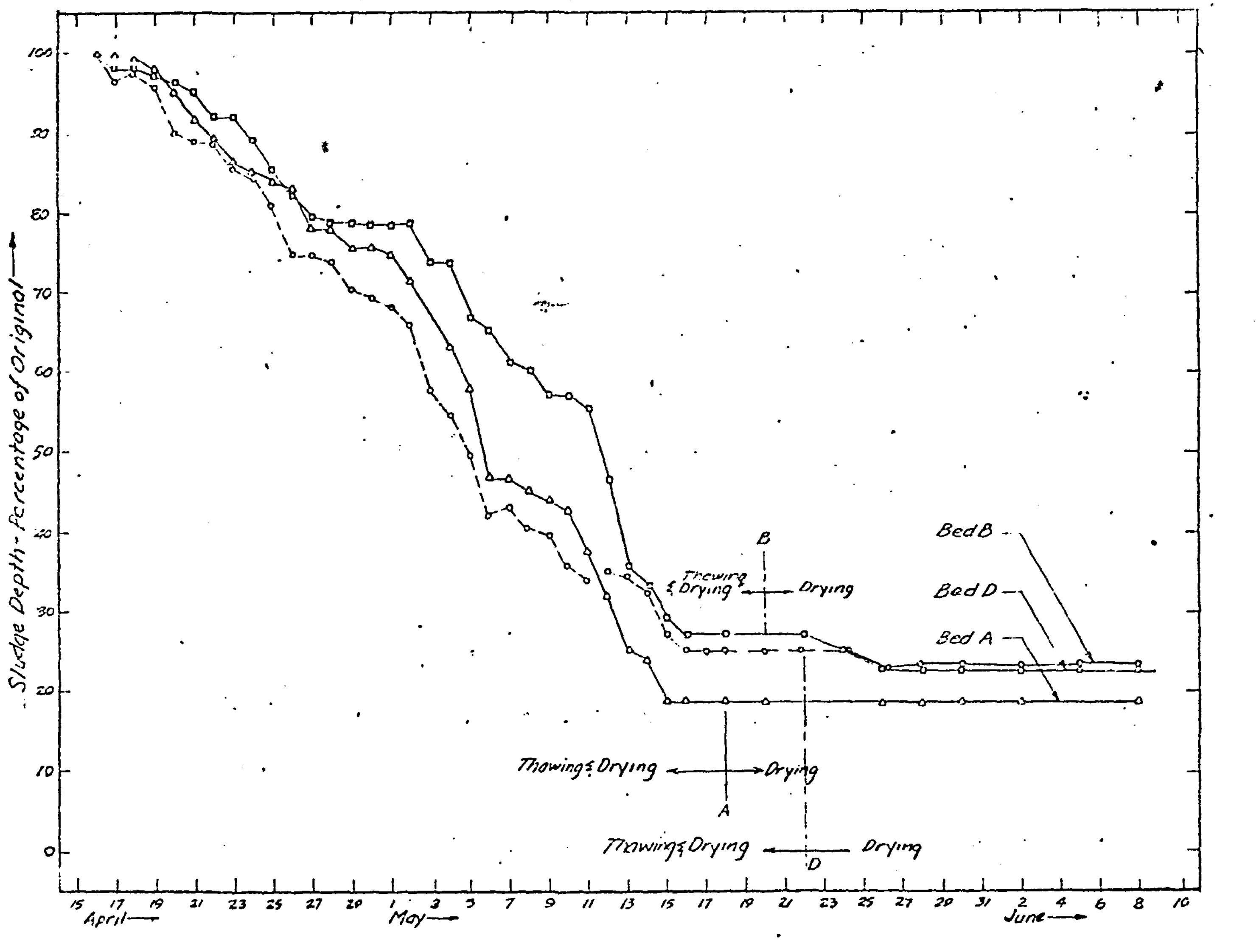


Figure No 33 Sludge Depth vs Time

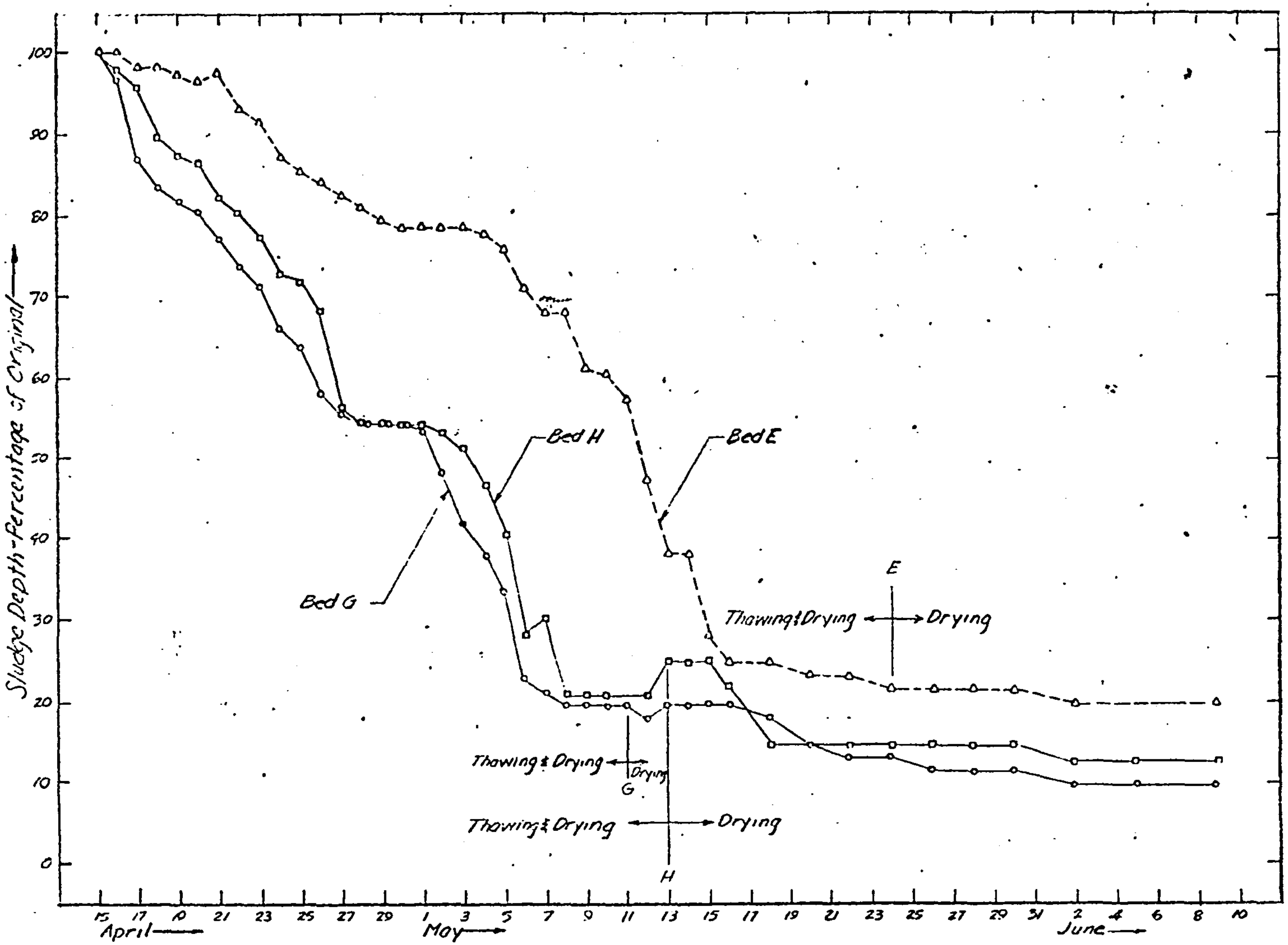


Figure No. 34 Sludge Depth vs Time

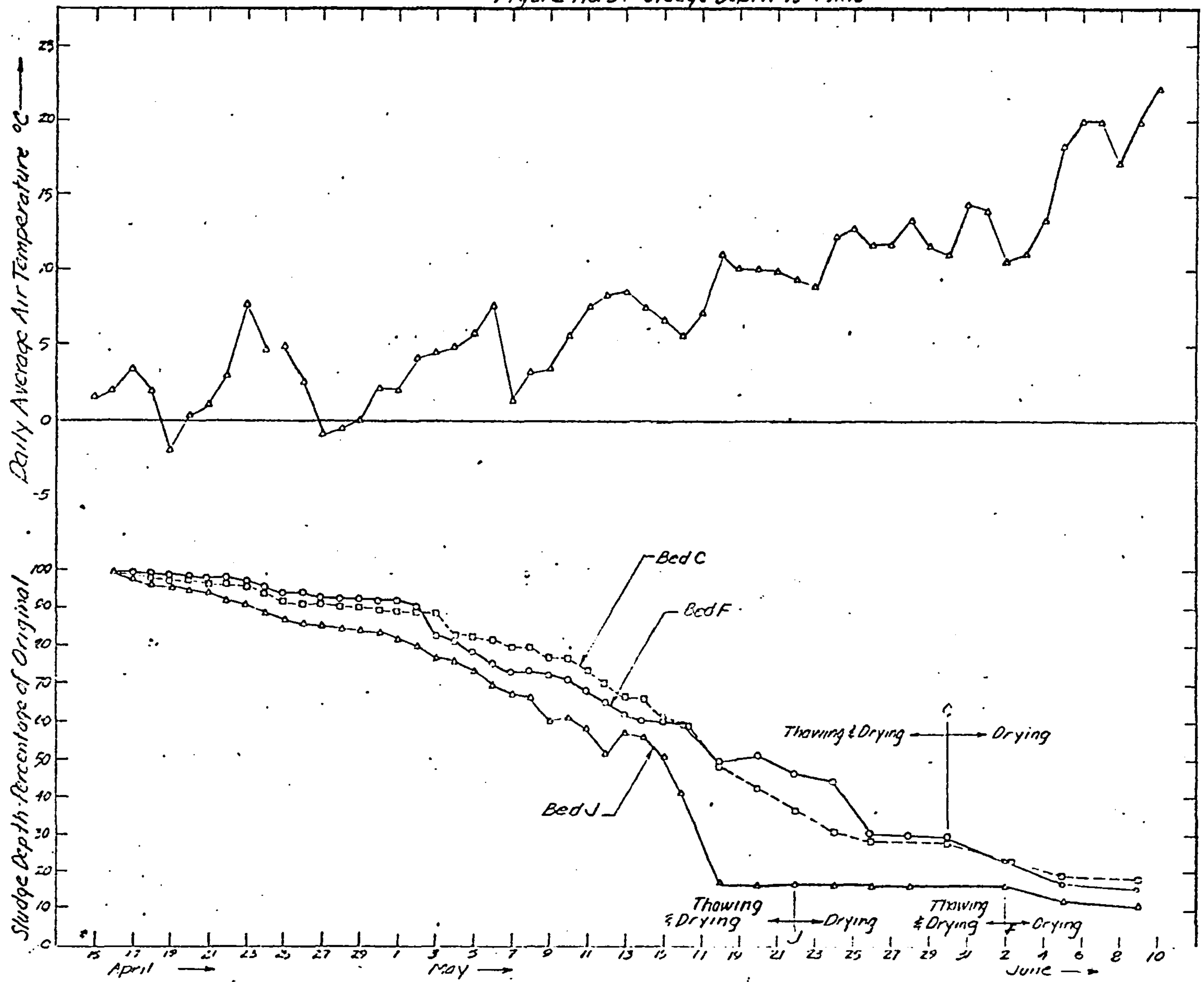


TABLE 9
FIELD THAW DATA - 21

DATE May 5, 1971 TIME: 4:00 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	5-3/8	1/16	1/2	Not much change.
B	3-3/8	1/16	3/8	Some ice shrinkage away from the walls.
C	17-3/4	3/4	1/4	Some ice shrinkage from walls. Damp spots through mold.
D	3-13/16	1/2	7/16	Not much change.
E	5-1/4	1/2	1/8	Same as D.
F	17-1/2	3/8	1/2	60% exposed sludge solids. Black solid ice below thawed layer.
G	1-15/16	5/8	3/16	95% exposed sludge sludge solids Still solid ice below thawed layer. Thawed to sand in NW corner - 2" depth.
H	1-13/16	5/8	1/4	99% exposed sludge solids. Thawed to sand in NW corner.
J	13-11/16	1/16	1/2	70% exposed sludge layer.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odor on site.
2. No sampleable liquid in any of the beds.

Table 10
SOLIDS CONCENTRATIONS AND SLUDGE DEPTHS

Bed	Solids Concentration (%) Initial (S_i)	Solids Concentration (%) Final (S_f)	Depth of Sludge (Inches) Initial (D_i)	Depth of Sludge (Inches) Final (D_f)	Ratios $\frac{S_f}{S_i}$	Ratios $\frac{D_i}{D_f}$
A	5.3	59.1	9.375	1.75	11.1	5.4
B	5.0	48.3	6.9375	1.625	9.7	4.3
C	5.5	31.6	21.8125	6.25	5.7	3.5
D	4.2	43.5	6.4375	1.5	6.3	4.3
E	3.8	60.9	7.5625	1.625	16.0	4.7
F	3.9	43.5	22.8125	6.875	11.1	3.3
G	1.9	91.3	7.625	0.875	48.1	8.7
H	2.0	86.3	6.0	0.875	43.1	6.9
J	1.9	39.7	18.75	3.0	20.9	6.3

Notes:

1. Neglecting voids and varying compressibility $S_i D_i = S_f D_f$.
2. Final depths reported for G, H may be too high due to curling of the tightly coagulated solids.
3. Actual final solids could be slightly less for all beds due to sand inclusion and bias in surface sampling. There was slightly more moisture at depth but it was difficult to sample at depth without getting sand in the sample.
4. There are voids and considerable variance in compressibility.

Table 11
DEGREE-HOURS (°C-hr) FOR COMPLETE FREEZING AND THAWING

		Complete Freezing		Complete Thawing	
	Bed	°C-hr	$\frac{°C\text{-hr}}{\text{inch-mg/l solids}}$	°C-hr	$\frac{°C\text{-hr}}{\text{inch-mg/l solids}}$
Run 1	A*	1265	25.2	-	-
	B	1872	54.0	-	-
	C	3184	42.6	-	-
Run 2	D*	1506	56.2	-	-
	E	-	-	-	-
	F	5536	62.3	-	-
Run 3	G*	579	39.8	964	65.9
	H	394	32.4	1434	117.7
	J	850	24.0	2550	71.9

*Uninsulated

Notes:
1. Thawing sludge much better insulator than freezing sludge.
2. Problems were encountered with the lowest thermocouple in Bed E; therefore, time for complete freeze cannot be calculated.
3. Thinner sludge requires less driving force for freezing than does thicker sludge; thermal conductivity is related to solids concentration.
4. Temperatures during thaw were not monitored in Beds A, B, C, D, E, F.

Table 12
NUTRIENT DATA

Soil Analysis

Sample Location	pH	lbs per acre available - 8" furrow NO_3	P_2O_5	K_2O
Fairbanks Area				
New Land - 1	5.7	50	26	94
New Land - 2	5.6	8	13	76
New Land - 3	7.7	55	127	177
New Land - 4	6.2	60	6	88
New Land - 5	6.7	95	0	135
Unfertilized worked land	7.9	14	2	94
Fertilized worked land	6.9	76	206	161
Delta Junction				
New Land - 1	6.0	82	13	253
New Land - 2	5.8	21	19	266
New Land - 3	5.2	39	20	275
New Land - 4	6.5	9	42	280
New Land - 5	6.0	22	53	280
Thawed and Partially Dried Sludge				
Sample C - 35.5% solids	6.7	350	16	280
Sample F - 36.8% solids	3.4	166	3	284
Sample J - 43.7% solids	6.4	350+	25	284
"Ball Park" optimum	-	80	40	320

Notes:

1. lbs/acre = ppm X 2
2. All analyses and information courtesy of District Agricultural Agent Co-operative Extension Service, University of Alaska. Samples C, F, J only samples collected pertinent to sludge project; other values were taken from files.
3. pH range for natural soils in Alaska pH 3.8 - pH 7.5. Mean pH approximately 5.6.

Table 13
INTERPRETATION OF NUTRIENT DATA

Tables 1, 2, 3 below indicate values of potassium, phosphorous and nitrogen to be used for turf grass management in the Anchorage area.

Table 1
Potassium

K_2O K-lbs/acre	Pounds to apply per acre	Descriptive Rating
0 - 120	100	Very low
180	80	Low
240	60	Low
300	40	Medium
340	20	Medium
360	0	High
520	0	Very high

Table 2
Phosphorous

P_2O_5-lbs/acre	Pounds to apply per acre	Descriptive Rating
0 - 10	100	Very low
20	75	Low
40	50	Low
60	30	Medium
80 - 200	20	High
>200	0	Very high
>400	0	Excessive

Table 3
Nitrogen

NO_3-lbs/acre	Pounds to apply per acre	Descriptive Rating
0 - 20	320	Very low
20 - 40	240	Low
40 - 80	200	Medium
80 - 140	160	High
140 - 200	40	Very high
>200	0	Excessive

All values and information from Co-operative Extension Division, University of Alaska.

period are incorporated in the Appendix; a discussion of these calculations is included in Chapter VI.

D. Miscellaneous Data

This section is devoted to miscellaneous experiments carried out with excess or additional samples of sludge. All the data for this section are incorporated in the Appendix.

Table 23 contains the results of a laboratory freezing experiment conducted on excess sludge from Run 2. Tables 24 and 25 show the results of the sand drying of raw and lab-frozen sludge, respectively. The results of a freezing study of excess sludge from the third run, comparing raw and alum-dosed sludge, are embodied in Table 26.

Table 27 illustrates drainability data for lab-frozen sludge while Figure 63 graphically represents the drainability data of selected sludge samples.

Figures 64, 65, 66, 67, 68, 69 and 70 contain settleable solids curves for various pretreatments of sludge in the laboratory and field. Laboratory freezing, field freezing and alum dosage of sludge are the major variables in these curves.

CHAPTER VI DISCUSSION OF THE DATA

The research data generally followed that generated by earlier investigators; however, the data discussed in this chapter are much more extensive than that surveyed in the literature. To ensure orderly discussion in the data, this chapter is divided into the same sections as was Chapter V; namely: raw sludge data, frozen sludge core data, field data and miscellaneous data. Some general conclusions are delineated at the end of the chapter.

A. Raw Sludge Data

1. Run 1

The data describing the raw sludge characteristics of Run 1 indicate a very thick sludge, a large percentage of which is non-biodegradable or inert. The BOD to COD ratio ranged from 0.175 to 0.326 and averaged 0.238. The low ratio is due to the fact that the return sludge line was plugged for two days prior to withdrawal of sludge in order to ensure a thick consistency. It is also likely that auto-wasting had not occurred for some time prior to sludge withdrawal. Auto-wasting occurs when the inert polysaccharides build up to an intolerably high level in an extended aeration activated sludge system. Sludge is washed out of the system via the effluent usually after an increase in the flow of the incoming waste water. This phenomenon was reported for the College Utilities oxidation ditch by Grube in 1968.[29]

The solids concentration ranged from 4.32% to 5.96% and averaged 5.29%. This is much thicker sludge than would be routinely withdrawn from a sedimentation basin and is due to gravity thickening. A normal range of solids concentration for secondary sludge is in the neighborhood of 0.2 - 1.5% total solids[30] for conventional activated sludge and 1.0 - 2.0% for the oxidation ditch process.[31] The sludge used in this run therefore was about 3 - 4 times as thick as sludge normally withdrawn from sedimentation basins. The volatile fraction ranged from 69.8% to 82.8% and averaged 76.4%.

The COD ranged from 52,380 mg/l to 65,180 mg/l and averaged 61,530 mg/l while the BOD ranged from 11,400 mg/l to 21,000 mg/l and averaged 14,600 mg/l. The pH varied very little in the samples; it ranged from 6.6 to 6.8 and averaged pH 6.7.

Inspection of the settleable solids data indicates that negligible settling occurred in the first 30 minutes of settling. Even after 24 hours the sludge interface had only settled a maximum of 115 ml in the 1,000 ml graduate cylinder. This very thick sludge was clearly in a state of compression as described in the classical paragenesis diagram.[32] Ideally, the settleable solids test would be conducted at the same temperature at which settling would occur; with the low temperatures encountered during sludge pouring this was not possible. In any case, it is pointed out by Reed and Murphy[32] that the influence of temperature on settling velocity decreases as the concentration of the activated sludge increases. The influence of temperature reportedly varies from full viscosity effects at very low concentrations to negligible effects at very high concentrations. The authors further state that the compression or thickening of sludge is independent of fluid temperature. This statement clearly applies to the sludge poured during all three runs in this project.

All samples were soupy, stringy, exhibited a slightly offensive odor and were gray in color. The odor was likely intensified by the prolonged storage of the sludge in the bottom of the sedimentation tank. Viewing under a 3D Microscope at 10.5 power showed a bulky, filamentous structure, apparently holding a great deal of bound water. The sludge had a jelly-like appearance. In general, the second sample taken for each bed was slightly thicker and contained more organic material than the first sample.

2. Run 2

The sludge used in Run 2 was withdrawn after the return sludge line from the clarifier was plugged for 18 hours. The sludge was thinner than that used in Run 1 but about twice as thick as that which would be routinely withdrawn in a prototype installation. The sludge was fresher, as evidenced by the higher BOD to COD ratio which ranged from 0.323 to 0.509 and averaged 0.414.

The total solids concentrations varied from 3.61 percent to 3.98 percent and averaged 3.86 percent. The volatile fraction is slightly lower than that in Run 1, ranging from 66.2 percent to 69.9 percent and averaging 68.4 percent of the total solids.

The COD ranged from 34,800 mg/l to 40,900 mg/l and averaged 37,700 mg/l while the BOD ranged from 13,200 mg/l to 17,700 and averaged 15,500 mg/l. Replicate analyses were run on the COD determinations and were found to be slightly erratic; this being due to the difficulty in pipetting two duplicate aliquots from a dilution mixture heavily laden with solids.

The pH of the sample varied little in the six samples; the range was from 6.90 to 7.01 and the average pH was 6.98.

The settleable solids test again illustrate the thick and bulky nature of the raw sludge. Very little settling was seen after one hour and the maximum settling after 24 hours was 210 ml.

The physical examination of the sludge from Run 2 indicated a gray, soupy consistency which was not as thick as the sludge from Run 1. Since the sludge was fresher the odor was not as pronounced as that from the first run. There is no distinct difference between the first sample and the second sample collected for a particular bed.

3. Run 3

The sludge from Run 3 was considerably thinner than that used in the first two runs and was closely indicative of that which could be withdrawn in practice. Since it was drawn from a higher elevation in the sedimentation basin, it was also much fresher sludge, as evidenced by the greatly increased BOD to COD ratio. The ratio ranged from 0.742 to 0.981 and averaged 0.902.

The total solids concentrations varied from 1.87 percent to 2.12 percent and averaged 1.94 percent. The volatile fraction was much the same as the first two runs ranging from 69.4 percent to 74.6 percent and averaging 71.7 percent.

The COD ranged from 14,500 mg/l to 23,700 mg/l and averaged 18,200 mg/l while the BOD ranged from 13,700 mg/l to 19,500 mg/l and averaged 16,300 mg/l.

The pH showed little variation among the samples, ranging from 7.63 to 7.71 and averaging 7.67.

The results of the settleable solids test indicated that considerable settling of this raw sludge would take place prior to freezing, although the sludge was still quite thick. After one hour the interface height varied from 920 ml to 950 ml in the 1,000 ml graduate cylinder. After 24 hours of laboratory settling the interface height varied from 410 ml to 550 ml. An analysis of the supernatant from the settleable solids test showed a BOD range of 98 mg/l to 760 mg/l and an average of 366 mg/l. The suspended solids ranged from 100 mg/l to 700 mg/l and averaged 367 mg/l.

There is no marked trend in comparing the analyses pertaining to the first sample taken for a particular bed to the second sample taken for the same bed.

The sludge was thinner and easier to pour than the sludge from the first two runs. The color was gray; the odor was not obnoxious but rather imparted an oily odor.

It is likely that the volatile portions of the total solids concentrations were influenced somewhat by the indiscriminate dumping of septic tank sludge into the oxidation ditch in the winter time. Some days the volume of septic tank sludge dumped represented 5-10% of the entire volume of the oxidation ditch.(33)

4. Drainability Tests

Figure 19 compares the drainability of random samples of raw sludge to the drainability of laboratory-frozen sludge. After 60 minutes 390 ml of water drained off a sample of raw sludge while 593 ml of water drained off a laboratory-frozen sample of the same sludge. A second sample of raw sludge yielded 317 ml of water in 60 minutes while a laboratory-frozen sample of the same sludge yielded 510 ml of water. The most remarkable effect of freezing sludge to increase dewatering is seen in the early stages of the test. For example, at 10 minutes a raw sample gave up 6 ml of water while a laboratory-freeze sample of the same sludge yielded 496 ml of water.

The drainability test is described in Figure 11 and Table 16.

B. Frozen Sludge Core Data

Graphical representations of pertinent frozen sludge core data are given in Figures 60A to 60Q in the Appendix. Photographs denoted as Figures 36 to 48 illustrate the macroscopic appearance of the intact cores and cores sections before and after thawing.

1. The Supernatant Phase

The pH generally decreased slightly with increasing depth of the core section as the suspended solids concentration increased. This could indicate a very slight amount of anaerobic digestion prior to and during freezing. The volatile portion of the suspended solids varied from 8.2 percent to 100 percent and averaged approximately 80 percent.

The BOD and COD generally increased with depth although some erratic results are apparent. This was caused by difficulty in obtaining representative samples of the supernatant. Some suspended solids sloughing off the dewatered solids invariably were included during pipetting of the samples. The values shown for BOD and COD are therefore conservative. Replicate samples could not be analyzed because the volume of supernatant for analyses was extremely limited. The BOD values ranged from zero to 3,210 mg/l while the COD values ranged from zero to 5,960 mg/l. The BOD to COD ratio ranged from 0.112 to 0.870. The range of BOD and COD values was extremely wide for any given core taken from the second and third runs. Cores from Run 2 and Run 3 had good clarity at the top six inches of the respective cores, as shown in Figures 37 and 38. Core C from the first run did not exhibit as much vertical disparity in BOD and COD values because the sludge did not settle appreciably prior to freezing. Figure 36 illustrates the uniform distribution of solids in core C except for a very thin section at the surface.

Cores from the first two runs contained considerable dissolved organics throughout the samples as apparent by the varying intensity of yellow color contained in their supernatant. The supernatant from the top sections of the cores of the third run were white while the bottom sections had yellow supernatant.

Total solids and total volatile solids determinations were performed on the supernatant from the third run core samples. With the total solids and suspended solids concentrations known, the dissolved solids concentrations were calculated. Core G1 shows a remarkable variation in total solids, 222 mg/l at the top and 3,476 mg/l at the bottom. Core H1 showed similar disparity between the top and bottom of the core. The dissolved solids varied from 209 mg/l at the top of Core G1 to 3,420 mg/l at the bottom.

Odor was noticed where total solids concentration were in the order of thousands; no odor was evident when the total solids were less than 1,000 mg/l.

2. Dewatered Solids Phase

Total solids and total volatiles solids determinations were conducted on samples of coagulated solids remaining after gravity drainage was completed. Figures 43, 45 and 47 illustrate the coagulated solids from which the "supernatant" had drained.

Comparing the total solids concentrations of these dewatered solids to the total solids concentrations of the raw sludge, that was poured into the beds from which the cores were taken, it is seen that the following increases in concentration were achieved:

Bed	Avg Initial Solids Concentration (%)	Dewatered Solids Concentration (%)	Factor of Increase
A	5.37	11.1 - 13.1	2.05 - 2.44
B	5.00	12.7 - 14.8	2.54 - 2.94
C	5.49	10.9 - 16.9	1.98 - 3.08
D	4.16	12.0 - 13.8	2.88 - 3.32
E	3.79	10.3 - 14.2	2.72 - 3.75
F	3.88	14.8 - 19.3	3.82 - 4.97
G	1.91	17.5	9.16
H	2.03	13.1 - 14.9	6.45 - 7.34
J	1.89	N.D.	-

Naturally, dewatered solids concentrations were not conducted for core sections where only relatively clear supernatant resulted from thawing. The core sample withdrawn for J did not include the settled solids portion of the sludge; these solids had not frozen. The field sampling allowed solids determinations for these solids (See Part C in this chapter). It is evident that the efficiency of dewatering is greatly increased as the raw sludge concentration is decreased.

The dewatered solids concentration is observed to increase slightly with increasing depth of the core section.

The volatile portion of the total dewatered solids ranged from 47.8 percent to 76.2 percent.

3. Water-Sludge Mixture Phase

This phase was subjected to total solids, total volatile solids and COD analyses in order to more precisely observe the variation of these parameters with depth in the nominal 18-inch cores.

Core C showed little variation from top to bottom; the total solids varied from 21,989 mg/l at the top to 46,240 mg/l at the bottom section.

Figure No. 35 - Final appearance of sludge in Bed F

Figure No. 36 - Core C1, undisturbed

Figure No. 37 - Core F1, undisturbed

Figure No. 38 - Core J1, undisturbed

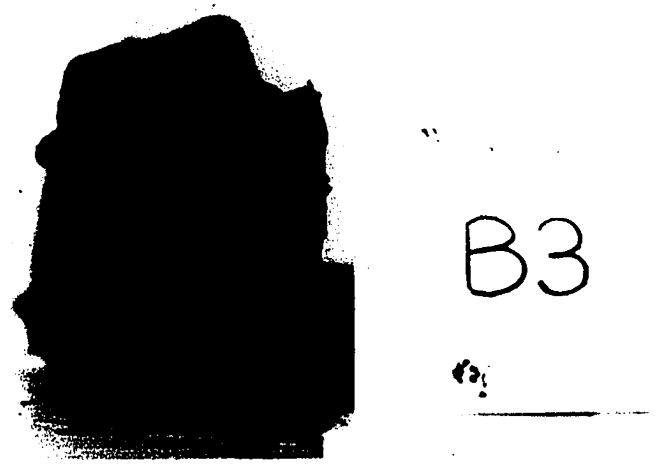


Figure No. 39 - Core B3, undisturbed

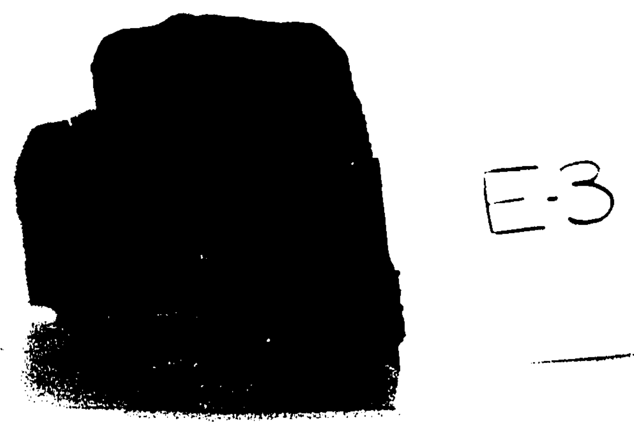


Figure No. 40 - Core E3, undisturbed

Figure No. 41 - Core H1, undisturbed

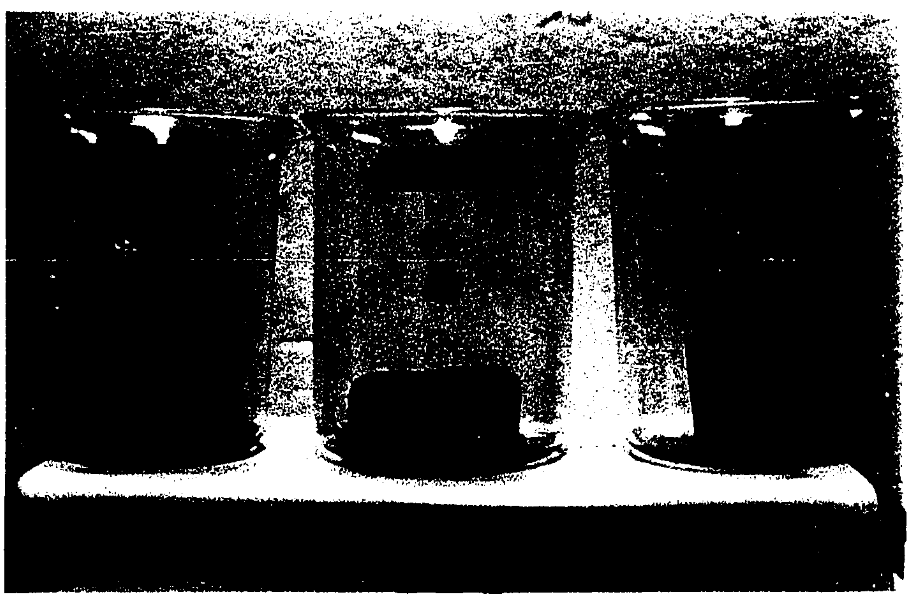


Figure No. 42 - Core C2, sectioned, before thawing.

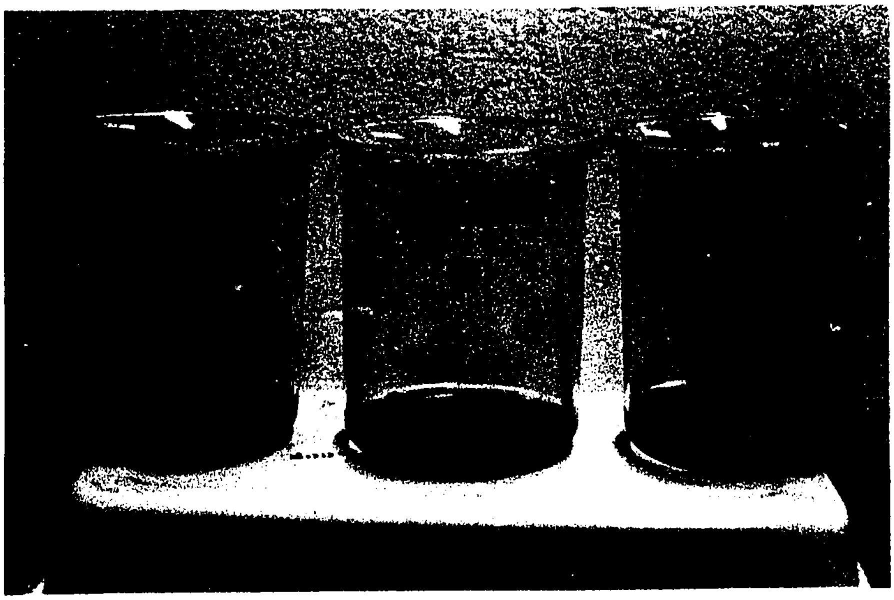


Figure No. 43 - Core C2, sectioned, after thawing

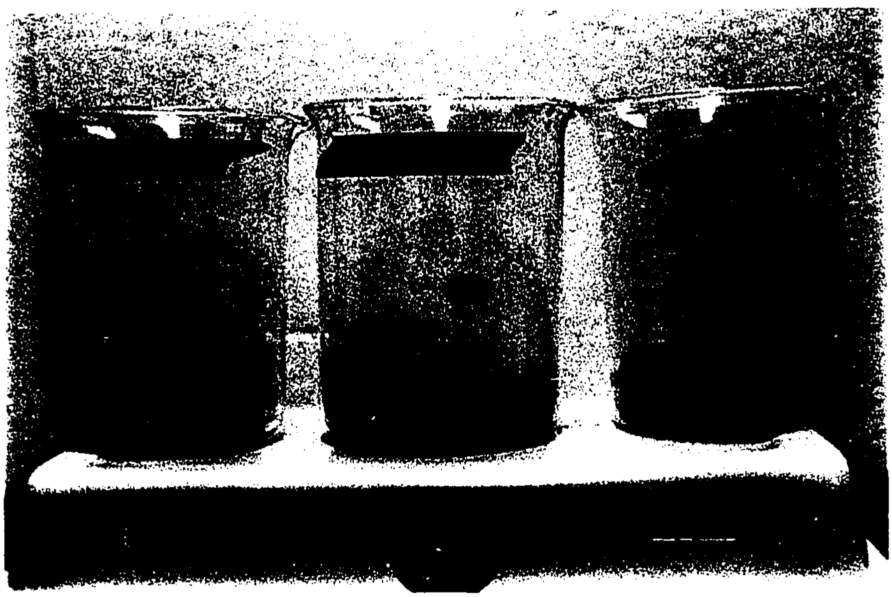


Figure No. 44 - Core E3, sectioned, before thawing

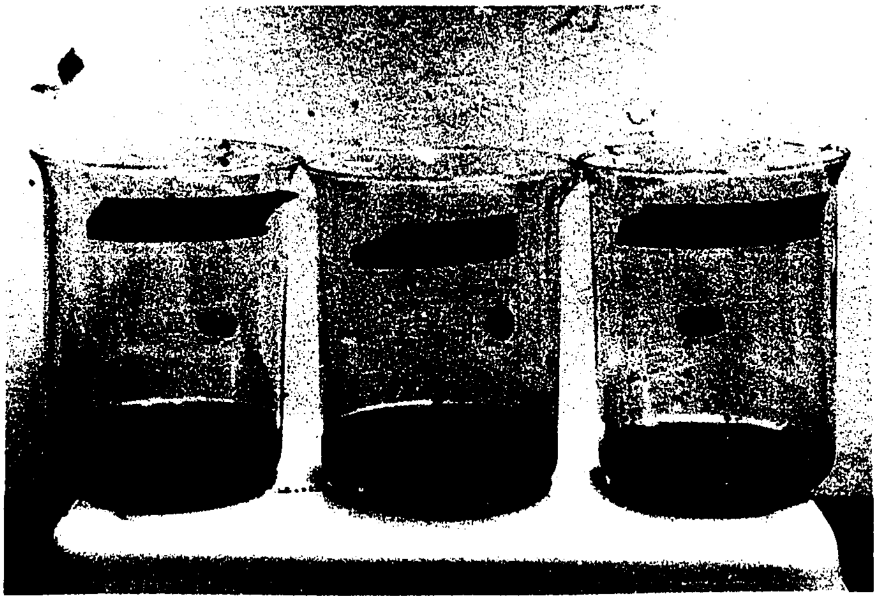


Figure No. 45 - Core E3, sectioned, after thawing

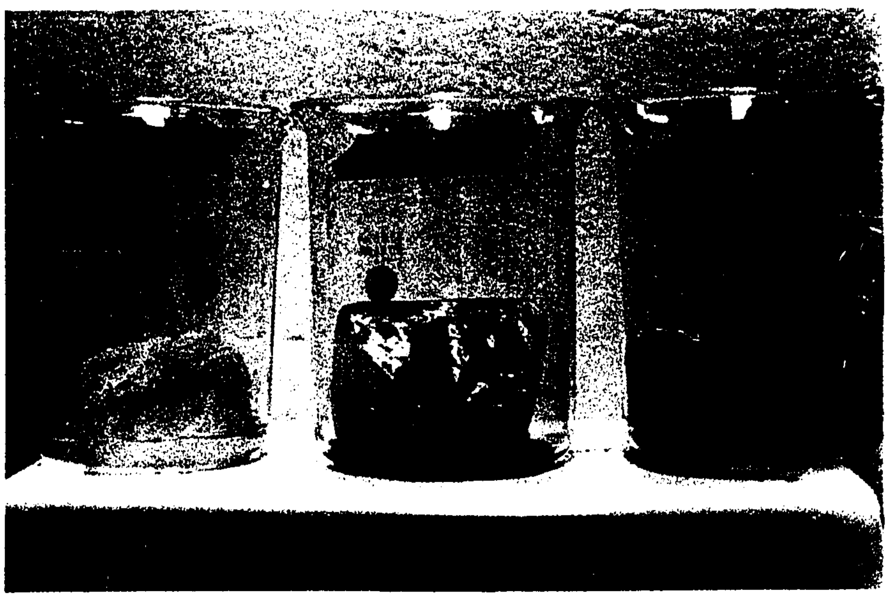


Figure No. 46 - Core H1, sectioned, before thawing

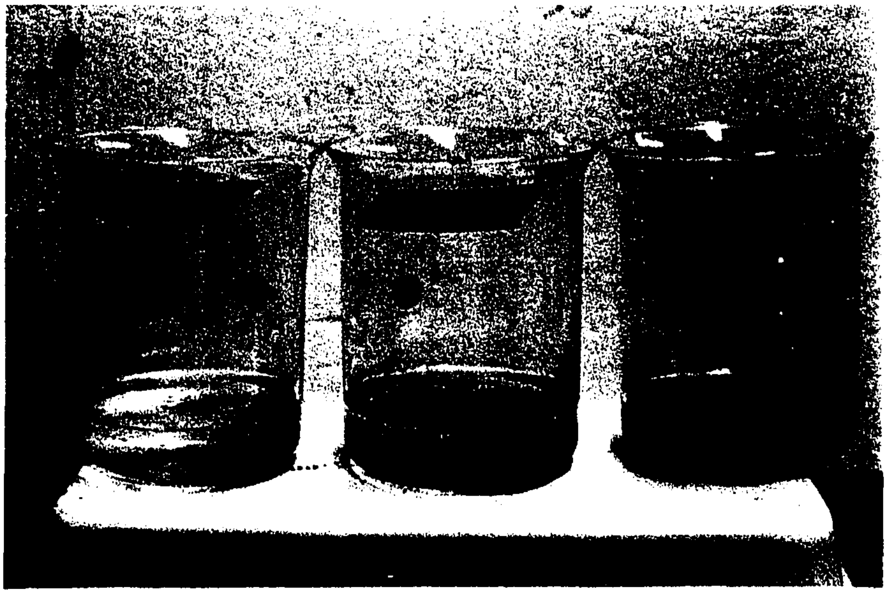


Figure No. 47 - Core H1, sectioned, after thawing

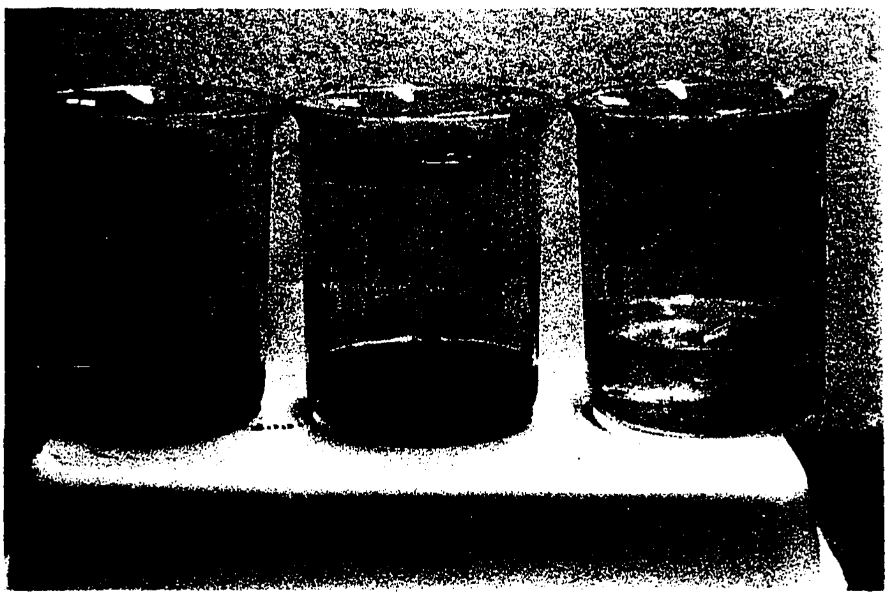


Figure No. 48 - Comparison of C2 top, E3 top, G1 top

The COD did not vary significantly considering the 100 fold dilutions used. Figure 36 is a photograph of Core C.

Core F had a much larger variation than Core C in total solids, ranging from 281 mg/l at the top section to 39,429 mg/l at the bottom section. Figure 37, a photograph of Core F, illustrates the vertical variation in solids concentration due to settling prior to freezing.

Core J did not comprise the total depth of sludge due to an incomplete freeze; the total solids ranged from 67 mg/l to 630 mg/l in the top seven inches. It should be noted that the dissolved solids must be relatively low as well; it is for this reason that the clarity of Core F was so excellent (See Figure 37). The COD varied from a zero reading at the surface to 20 mg/l at the four-to-seven-inch depth section; these low COD values testify to the low concentration of organic material in this core.

4. Settleable Solids and Drainability

Aliquots of the full vertical extent of cores C, F and J were preserved for further analyses - namely, a settleable solids test and drainability tests. Core J had too few solids to show a sludge interface in the settleable solids test and to do a meaningful drainability test.

The results of the settleable solids test are given in Figure 60A. It is apparent that freezing remarkably increased the settleability of the sludge poured into Beds C and F. The interface dropped very rapidly and settling was virtually complete in ten minutes. The thinner sludge, sample F at 3.88 percent solids, had a lower interface than sample C at 5.49 percent solids. The effect of freezing is appreciated by comparing Figure 60A to Figure 14. The interface height of the freeze-treated sludge is

505 ml after 30 minutes; for raw sludge virtually no settling had occurred after 30 minutes. The freeze-treated sludge underwent more than twice as much solid-liquid separation in ten minutes as the raw sludge did in 24 hours. Similar observations can be made for Core F by comparing Figure 60A to Figure 17.

Drainability tests were not conducted on the samples of raw sludge poured into the beds. However, these tests were carried out on random samples of raw sludge collected later in the project. The results of these are shown graphically in Figure 63. This figure compares the drainability of various concentrations of raw sludge to the same samples of sludge after being subjected to laboratory freezing. Also included in this figure are the results of drainability tests conducted on core samples C and F. It is apparent that site freezing greatly improves the drainability of thick sludge. The laboratory freezing improved the drainability but not to as much of a degree as slow, field freezing. From the data it is apparent that thin raw sludge is significantly drainable.

5. Miscellaneous

The portions of Cores C2, E3 and H1 which were remaining after the other analyses were completed were subjected to 18 hours of sand drying on three inches of sand contained in five pound coffee cans. The sludge dried very well to a solids concentration of 55.9 percent for C2, 41.4 percent for E3, and 46.1 percent for H1. It is thus seen that freeze-treated sludge, when allowed to thaw and undergo gravity drainage, will dry to a handleable condition in a very short period of time. Laboratory manipulation showed that it appeared that application of a small amount of pressure to the dewatered solids could achieve much the same effect in even a shorter period of time.

The addendum to Table 28 discusses some of the finer details pertaining to the core analyses.

C. Field Data

1. Temperatures

Average daily air temperatures during the first run varied from -30°C to -4.8°C; from -30.6°C to -2.7°C during the second run and from -14.8°C to -0.7°C during the third run. These averages simply represent arithmetical averages of all temperatures tabulated on a given day. The thaw was considered to commence April 13, the first day that the average air temperature rose above 0°C. On three occasions after April 13 the average daily air temperature dipped below 0°C; namely on April 19 (-0.9°C), April 27 (-1.0°C) and April 28 (-0.6°C). The thawing of the sludge in all the beds was complete by June 2. The maximum daily average temperature during this period was 14.4°C.

The temperature data is most conveniently appreciated by viewing graphical representations of this data contained in Figures 21, 22 and 23 for the first run, Figures 24, 25 and 26 for the second run, Figures 27, 28 and 29 for the third run.

Figure 21 shows the effect of the air temperature on the sludge temperature at various locations in Bed A. The effect is most pronounced in the first six days of the freeze when the driving force, ΔT, is at its maximum. After the sludge and air temperature came into an equilibrium condition, on February 18, the sludge temperature simply lagged behind the air temperature. The response of the sludge temperature to air temperature decreased as the distance of the sludge from the surface of the bed increased. It appears that most of the heat transfer was through the surface of the bed while a smaller amount of heat was lost through the walls. This was to be expected in a six-inch nominal depth bed.

Figure 22 is similar to the curves plotted for Bed A; Figure 22 is drawn from the temperature data pertaining to Bed B. Again the equilibrium effect occurred after the sludge and the air temperature became equal. The lag was more lengthy for thermocouple points located more distant from the surface of the bed. Again, most of the heat loss appeared to be through the bed surface. Bed B took one day longer to completely freeze than did Bed A; this was because Bed B was insulated, which would minimize heat loss through the walls.

The curves for Bed C in Figure 23 show that the heat loss through the walls for an 18-inch nominal depth bed was much higher proportionately than that for the six-inch nominal depth beds. The thermocouple located on the centerline, 12-inches from the sand, took approximately five days to reach freezing temperature while the thermocouple located one inch from the sand took only 2.2 days to reach zero degrees centigrade. This would also suggest that there was significant heat loss through the bottom of the bed. The sludge temperature measured by a thermocouple 12 inches from the sand and 9.8125 inches from the surface was very slow in responding to air temperatures.

Figure 24 indicates that thinner sludge in Run 2 was more responsive to air temperature fluctuations than was the thicker sludge in Run 1. These curves pertain to temperatures measured in Bed D. It was noted that the curve for the temperatures recorded by a thermocouple located one inch from the wall and one inch from the sand very closely followed the curve for the temperatures measured by a thermocouple on the centerline five inches from the sand. This would indicate again that most of the heat loss was through the surface, even on this uninsulated bed. The centerline thermocouple, one inch from the sand and 5.4375 inches from the surface was considerably slower to reach 0°C than the others.

Figure 25 is quite similar to Figure 24 which was drawn for Bed D; Figure 25 represents temperatures measured in Bed E. This would suggest that the two inches of polyurethane had little effect on the freezing progress in the six-inch nominal depth beds.

Figure 26 illustrates the average daily temperatures computed for the thermocouples located in Bed F, the nominal 18-inch depth bed for Run 2. The slowest thermocouple to indicate the freezing temperature was the centerline thermocouple, 14.8125 inches from the surface. This thermocouple took nine days to indicate 0°C. The centerline thermocouple, one inch from the sand and 21.8125 inches from the surface was much quicker to indicate the freezing temperature, taking 3.1 days. This would suggest that either sludge is a better insulator than frozen sand or that some digestion was taking place at the center of the bed to prevent it from freezing. The former is likely to be the case.

Both freezing and thawing are illustrated for the third run beds as follows:

Figure 27 - Bed G
Figure 28 - Bed H
Figure 29 - Bed J

The slopes of the curves prior to the freezing point give an indication of the freezing rate. It is seen again that thinner sludge was more responsive to fluctuations in air temperature than thick sludge.

Figure 27 graphically illustrates average daily temperatures computed for Bed G. A distinct increase in lag times is seen as the distance from the surface of the bed increases. A comparison of the curves for the temperatures recorded by a thermocouple located on the centerline at a one inch distance from the sand and the thermocouple located on the wall one inch from the sand indicates that there was significant heat transfer through the walls in this bed. The separation in time of the crossing of the 0°C line by the curves suggests that thawing sludge is a better insulator than freezing sludge. The thermocouples located closest to the surface of the bed recorded the thawing temperature before the deep thermocouple locations.

Figure 28 is quite similar to the one drawn for Bed G; this figure is drawn to illustrate the temperature profile as measured by the thermocouples in Bed H. Again the thawing times show considerably more disparity than the freezing times. Comparison of the curve for thermocouples recording the temperature on the wall, five inches from the sand, and one inch from the surface and the curve for the temperatures recorded by a thermocouple on the wall, one-inch from the sand, to the other curves indicates that on this six-inch nominal depth bed most of the heat loss was through the surface of the bed. As indicated previously, the thermocouples recording sludge temperature closest to the bed surface showed the quickest response to air temperature fluctuations.

Figure 29 compares well with observations made on the other beds; these curves are drawn from the temperature data taken from Bed J. Again it is shown that thawing sludge has much better insulating properties than freezing sludge. Clearly, the thermocouples recording temperature closest to the surface are most directly influenced by changes in the air temperature. The thinner sludge used in Run 3 was frozen much more efficiently than the thicker sludge used in Run 1 and Run 2. The greater disparity in the thawing times for various thermocouple locations as compared with the thawing times was likely due to two factors:

1. Thawing sludge had better insulating properties than freezing sludge.
2. The driving force for thawing was much lower than the driving force for freezing.

The temperature data is sufficient and accurate enough for development to a much more sophisticated degree than done herein; however this development is beyond the scope of this project. The only further development in the temperature data is done in Table 11. Therein is noted the degree-hours required for complete freezing and thawing. The accuracy of the computations are tempered somewhat by the insufficient number of thermocouples used during the first two runs.

For Bed G it was found that thawing required 1.6 times the degree-hours that freezing required; Bed H thawing required 3.6 times that for freezing while Bed J thawing required 3 times as many degree-hours for thawing as for freezing. Further explanations of these computations are included as footnotes to the table. It is apparent that thinner sludge requires less quantity of driving force to effect freeze and thaw than does thick sludge.

2. <u>Relative Humidity and Evaporation</u>

The relative humidity data contained in Table 20 showed a range in relative humidity from 10 percent to 75 percent and an average of 33.2 percent. The afternoon air temperatures measured from May 6 to June 2 ranged from 38°F to 71°F and averaged 59.7°F. The weather conditions were generally partly cloudy with a light wind. From these data and other data furnished by the National Weather Service at Fairbanks International Airport it was calculated that evaporation could absorb 6.36 inches of moisture from the beds during the month of May. The formula used in the computations were taken from Chow.[36] It was concluded that evaporation could handle all the released moisture from the nominal six-inch beds and about half of that from the nominal 18-inch beds during May. The sand on the 18-inch beds would have to receive the remainder of the moisture during the month of May.

3. Thawed Sludge Samples

Tables 21A to 21X contain comprehensive data regarding the physical condition of sludge samples collected throughout the thaw period. These tables show the total solids and total volatile solids concentrations as well as the physical characteristics of the sludge on a given sampling day. The sludge which had been subjected to one freeze thaw cycle was generally gray-black in color and imparted an earthy, musty odor. The only exception was an occasional sample from Bed F or Bed J which exhibited slight odor. It is apparent from these data that Bed F underwent some anaerobic decomposition and that Bed J did not freeze throughout its entirety. Figure 31 graphically illustrates the history of total solids concentrations in the beds. Early peaks in the graphs, especially on April 30 in Beds D and E, show extra dehydration due to a surface nocturnal freeze. Generally, the solids concentrations did not show a drastic increase with time as moisture was continually being released by the frozen sludge into the thawed layer. Beds G and H showed early high solids concentrations, 93.1 percent and 84.6 percent, respectively on May 24 due to the direct drying energy imparted by the sun's rays. The moisture was released much more slowly from Beds D and E, which were never subjected to direct radiant energy from the sun. The volatile fraction of the sludge varied from 31.0 percent to 100 percent. Generally, the volatile solids concentration was about 60-65 percent of the total solids concentration. Bed J usually exhibited a lower volatile fraction than the others due to the inevitability of getting sand inclusion in the sample during the late stages of the thaw. This was due to the very thin layer of final sludge remaining in Bed J.

Physical examination of the samples from Bed J indicated that a portion of this bed did not freeze. The unfrozen sludge was cohesive and plastic as compared to the earthy, easily broken freeze-treated sludge.

Extended field drying appeared to result in a gradual lowering of the volatile fraction of the sludge. The odor emanating from Bed J decreased as the sludge experienced extensive drying. The sludge after freezing, thawing, and drying to approximately 30 percent solids concentration was very manageable, being forkable and free of obnoxious odors. It resembled the consistency and odor of organic peatsoils.

4. Field Thaw Data

This extensive data which is incorporated in Appendix III are, for the most part, self-explanatory. Basically these data contain daily sludge levels, sludge condition, site condition and extent of thaw. The quantitative portion of these data, the sludge depths, is graphically represented in Figures 32, 33 and 34 in Chapter V.

Figure 32 indicates that most of the volume reduction in six-inch nominal depth beds A, B and D took place between April 15 and May 15; the most rapid rate of volume reduction occurred during the period of May 1 to May 6. There was very little volume reduction in any of these beds after May 15.

Figure 33 illustrates volume reduction rates for the remaining six-inch nominal depth Beds, E, G and H. This figure illustrates that Beds

G and H thawed much more thoroughly and earlier than Beds A, B, D and E due to the direct radiant energy from the sun. The majority of the thaw is summarized as follows:

Bed G: 77.1 percent between April 15 and May 6
Bed H: 79.2 percent between April 15 and May 8
Bed E: 75.2 percent between April 15 and May 16

The thaw patterns for Bed G and Bed H were similar; the steepest rate of volume reduction for both occurred between May 1 and May 6. The maximum rate of thaw for Bed E occurred during the period of May 11 to May 15.

It is noteworty to mention that the thaw appeared to occur in a series of pulses. This thaw pattern was due to the self-insulating quality of the sludge. As the thaw progresses to a given degree, an insulating layer will be formed which will require a greater temperature driving force to overcome. The temperature driving force also is applied in a pulsating manner.

Figure 34 illustrates the thawing pattern for the three 18-inch nominal depth Beds, C, F and J. This figure shows that Bed J thawed much more rapidly than C and F; this is due to the fact that thinner sludge is more responsive to temperature changes and that Bed J received more direct sunlight than Bed C and F. The 18-inch beds exhibit a steadier and slower pattern of thaw than the nominal six-inch beds. Bed C and Bed F exhibited virtually the same pattern of thaw.

The significant points to be emphasized from these data are as follows:

1. Thin sludge thawed much more efficiently than thick sludge.
2. Direct radiant energy from the sun could be used to advantage during the thaw.
3. The sludge can be removed before advanced drying sets in.

The observation of the effectof solids concentration affecting thermal conductivity is supported by Alter[34] who states that the heat transfer coefficient for thin sludge is twice as great as that for thick sludge. He reported a heat transfer coefficient of 30 BTU/ft^2-hr.°F for thin sludge and 8-15 for thick sludge.

To substantiate the qualitative field thaw data the following highlights are enumerated:

1. Beds G, H and J had very clear ice at the surface of the beds; the solids were concentrated below. The remaining beds, with the exception of F, had the solids more uniformly distributed in vertical extent.

2. There was never any observed flow from the perforated drainage pipes installed in the nominal 18-inch depth Beds C, F and J. Moisture not handled by evaporation was absorbed by the sand, although the sand was observed to be quite dry and clean at the termination of the field program.

3. On only one occasion was an obnoxious odor sensed in the vicinity of the beds. For the remainder of the time the odor on the site was, at the worst, musty.

4. Beds A, C and F showed considerable heaving after the freeze. Figure 52 illustrates heaving in Bed A during the winter time.

5. Beds A, B and C supported the growth of a grey fibrous mold which grew to a maximum depth of 1/2 inch, covering the surface of these beds. This mold was significant in that it served as a good insulator and impeded the thaw in these beds. This mold as illustrated in Bed A in Figure 54 and in a close-up photograph in Figure 55.

6. None of the beds, of 2" x 4" and 3/4" plywood construction, suffered ill effects from the one freeze-thaw cycle implemented on raw sludge therein.

7. The surface of the beds never were covered by any more than 1/8 inch of liquid on any occasion, except on three days in late April. Usually the surface of the beds were scarcely damp to the touch. This observation conforms to predictions made by Alter(34) and observations made by Babbitt and Schlenz.(15)

8. Surface thawing appeared to advance three-dimensionally.

9. Only very thin layers of sludge at the surface of the beds experienced more than one freeze-thaw cycle. An additional cycle was experienced on Beds D, E, G and H on April 27 due nocturnal freezing.

10. Local site flooding due to excessive snowmelt did not affect the beds proper although it made their access unwieldy on occasion. Figure 56 illustrates the site during the initial stages of thaw.

11. The sludge solids in G, H and J were observed to be distinctly separated from the clear ice above them. Figure 58 illustrates this physical separation in Bed H. Figure 57 is a photograph of Bed H during the initial stages of thaw showing the clear ice at the surface of the bed.

12. The final appearance of the sludge was a tightly coagulated and solid mat with good cohesion. Figure 59 shows the final appearance of the sludge in Bed G.

13. Core sampling caused some disturbance of the clear ice by introducing solids from the bottom of the bed thereto.

14. Sublimation did not appear to be a major process occurring in the beds.

15. The gravel foundations for Beds C and F failed due to the quicking condition of the gravel caused by excessive local snowmelt. The failure caused these beds to tilt south allowing the influx of considerable radiant energy from the sun. This undoubtedly hastened the thaw in these beds. Furthermore, if the surface of the beds were never disturbed to withdraw sludge samples, the thaw would have taken even longer. The time for complete thaw of the beds was as follows:

Bed	Thaw Period	Days
A	April 13 - May 18	35
B	April 13 - May 20	37
C	April 13 - May 30	47
D	April 13 - May 22	39
E	April 13 - May 24	41
F	April 13 - June 2	49
G	April 13 - May 12	29
H	April 13 - May 16	33
J	April 13 - May 22	39

16. An increase in air temperature was followed firstly by an increase in thaw and wetter solids at the surface. This is because moisture was released faster than evaporation could take care of it.

17. The six-inch nominal depth beds could be easily cleared of sludge prior to complete thaw by breaking the fragile, rotten ice and removing it to dewater elsewhere.

18. After thawing, the sludge dried, shrunk and curled away from the sand, making its removal rather simple. However, a small amount of sand, perhaps 1/8 inch would be lost with each sludge removal.

19. Nuisance organisms in the form of worms or flies were not observed in the beds; a white fungus was observed growing in Bed A on June 17.

20. Drying beyond 40-50% solids concentration in the beds produced a very hard surface on the sludge similar to dried clay. The sludge would be easier handled in a slightly wetter state, especially if it were to be removed with a fork.

5. Liquid and Ice Samples

Samples of liquid on top of the sludge beds were taken on three occasions; further sampling was impossible due to lack of liquid. In lieu of liquid samples, ice samples were taken, thawed and analyzed to document the clarity of the ice. The purpose of these experiments was to determine the quality of the drainage water to be piped back to the waste treatment plant in a prototype freeze-thaw installation. A potent slug of drainage water would be an organic shock to a small biological waste treatment plant.

Liquid samples collected from Beds H and J proved to be approximately two to three times the strength of raw domestic sewage in terms of BOD, COD and suspended solids. The liquid from Bed J, sampled April 20, had a dissolved solids concentration of 980 mg/l while sample H showed a dissolved solids concentration of 1,885 mg/l. The color of sample J was much whiter than sample H, testifying to its lower concentration of dissolved organic solids. Samples collected April 23 from Bed H and J showed dissolved solids concentrations of 1,860 mg/l and zero respectively. It would appear that the rejection of dissolved contaminants occurred while the nominal 18-inch depth Bed J froze. The April 23 liquid samples

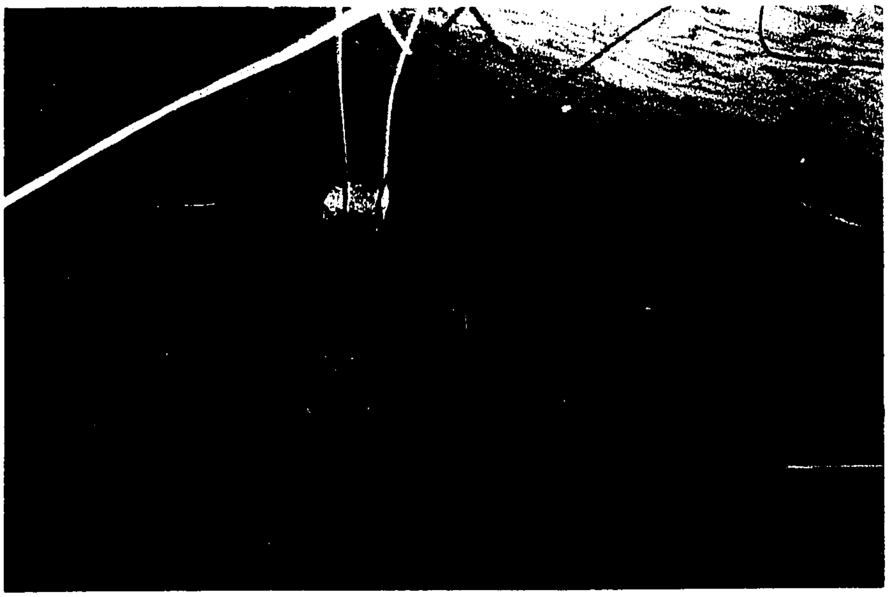


Figure No. 49 - Freshly poured sludge

Figure No. 50 - Frozen and heaved sludge Bed A

Figure No. 51 - Core hole in Bed F

Figure No. 52 - Psychrophilic mold and heaving in Bed A

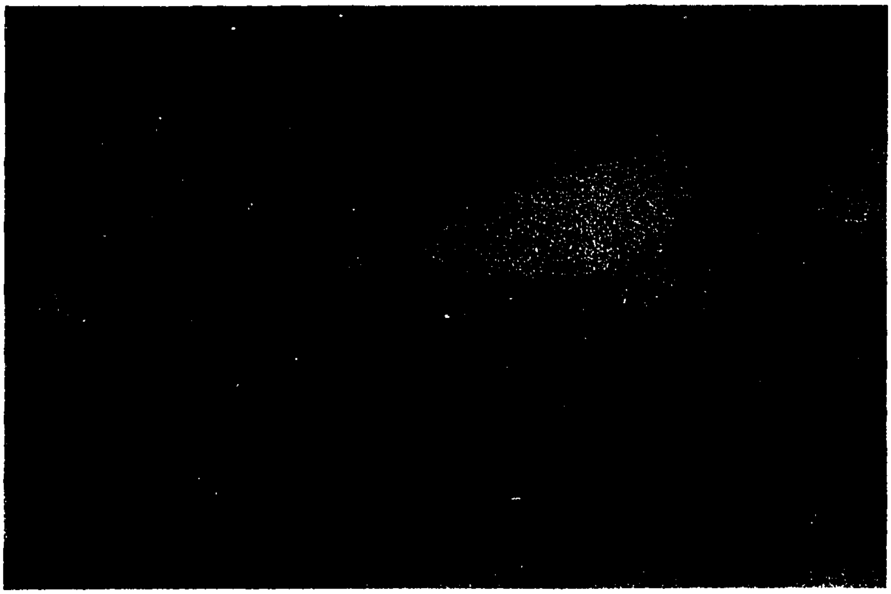


Figure No. 53 - Close-up of fibrous mold

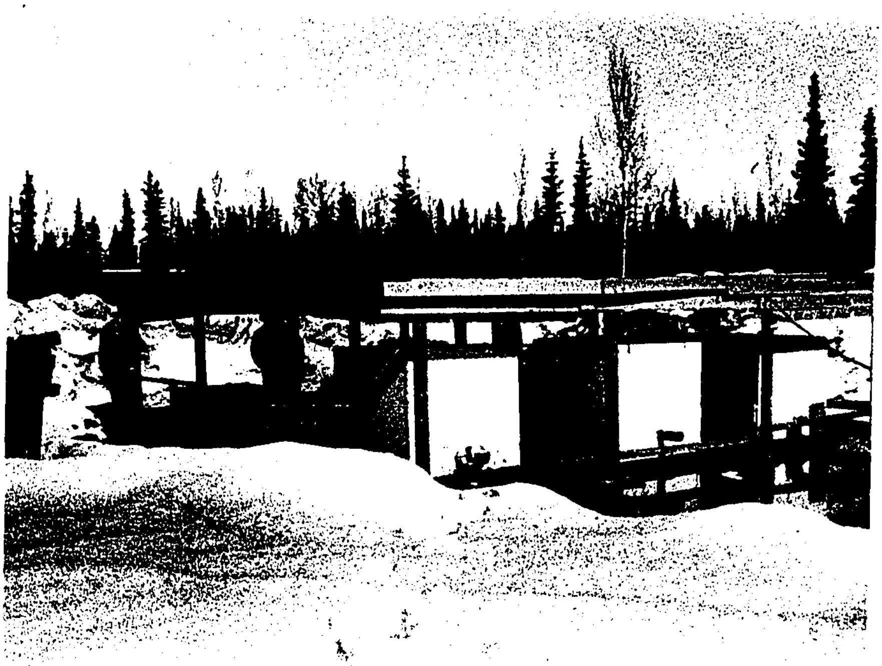


Figure No. 54 - Site during initial stages of thaw

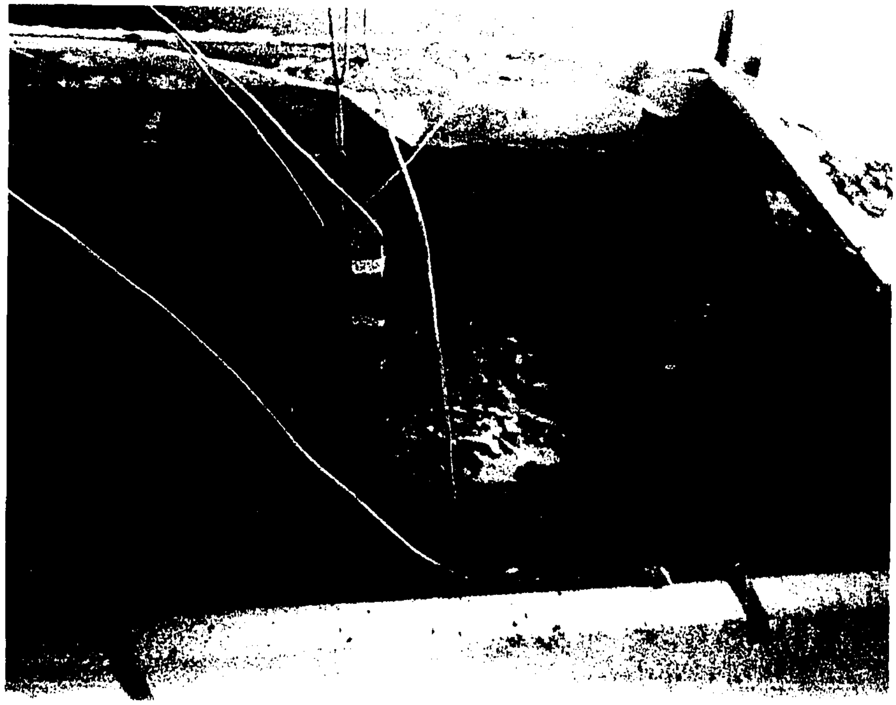


Figure No. 55 - Bed H during initial stages of thaw

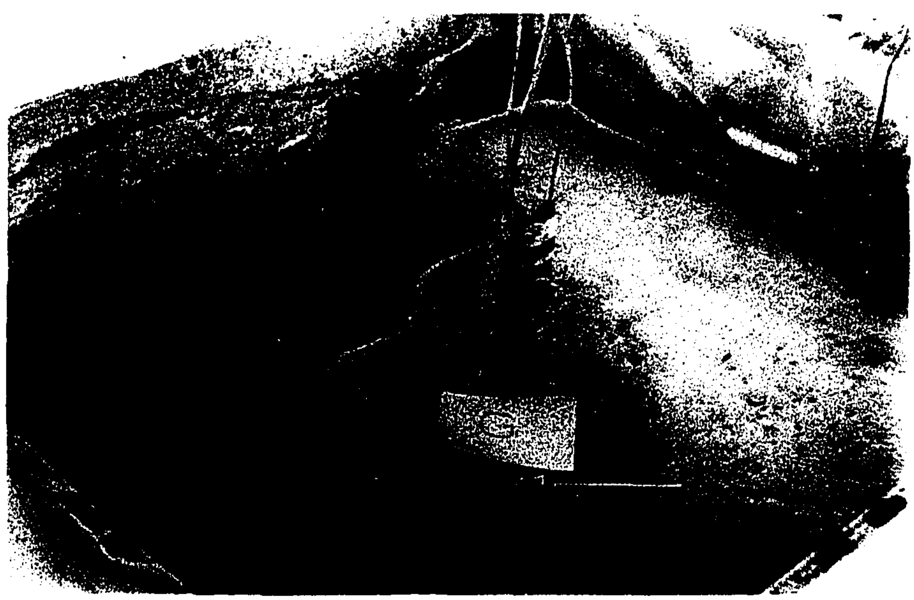


Figure No. 56 - Bed G during advanced thaw

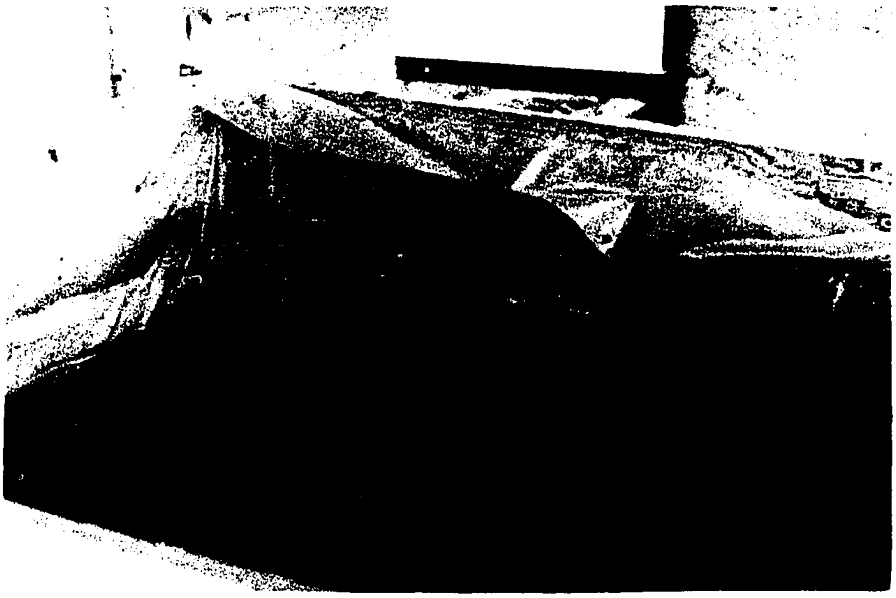


Figure No. 57 - Final appearance of sludge in Bed G

Figure No. 58 - Tightly coagulated sludge solids in six-inch bed showed BOD and COD values for sample H of 470 mg/l and 914 mg/l, respectively, with a suspended solids concentration of 1,530 mg/l. Sample J had BOD and COD concentrations of 235 mg/l and 560 mg/l respectively, with a suspended solids concentration of 1,324 mg/l. The strength of this liquid is approximately two to three times the strength of domestic waste and could easily be handled organically by a small biological waste treatment plant.

The ice samples collected from the top of Beds F, G and H April 23 showed suspended solids concentrations of 148 mg/l, 58 mg/l and 112 mg/l, respectively. Dissolved solids were very low for these samples; namely, 266 mg/l for F, 786 mg/l for G and 156 mg/l for H. Ice samples collected from Beds F, G and H on April 22 showed slightly higher suspended solids concentrations, approximately the same as those expected in raw domestic sewage.

On April 29 ice samples were taken from the top 1-1/2 inches of Beds C, F and J. The results testify to the remarkable increase in clarity progressive from the first run to the third run. Bed C had a total solids concentration of 33,127 mg/l, Bed F had a total solids concentration of 765 mg/l while Bed J contained only 239 mg/l. The BOD and COD concentrations followed similar trends. Again, the dissolved solids concentration in Bed J proved to be zero.

6. Sludge Depth and Solids Concentration

From the field thaw data and solids concentration data, an attempt was made to correlate sludge depth and solids concentrations by utilizing a mass balance. Table 10 shows that the correlation is less than perfect. Theoretically, the ratio of final solids concentration to initial solids concentration should equal the ratio of initial depth to final depth. Relatively close correlations were obtained for Beds A, B, C and D. The other beds showed poor correlation. The major difference would be caused from neglecting compressibility and air voids. Sand inclusion during sampling would affect the final solids concentration figures of Beds G, H and J. There was also bias in the surface sampling of Beds A, B, C, D, E and F. There was increasing moisture with depth but depth sampling was difficult to accomplish without obtaining sand inclusion. The final depths reported for G and H may be too great due to the curling of the tightly coagulated solids.

7. Nutrient Data

The nutrient data illustrates that the freeze-treated sludge had good nitrate and potash contents but was slightly low in phosphates. The pH and nitrate concentration of the sample taken from Bed F are significantly low suggesting that some anaerobic decomposition may have taken place therein, probably during the thaw. Comparing the sludge to the unworked native soils one can see that the sludge could be resourcefully used as a soil conditioner. Using the arbitrary scale set up by the Co-operative Extension Service of the University of Alaska the sludge sample is "medium" in potash value, "low" in phosphate and "excessive" in nitrates.

D. Miscellaneous Data

The results of the settleable solids test applied to laboratory-frozen excess sludge from Run 2 show that a tremendous increase in settleability was effected even by subjecting the sludge to a quick three-dimensional freeze. This pronounced effect is shown in Figures 64, 65 and 66. It can be seen in Figure 37 that, after 60 minutes of settling, the height of the sludge interface was 990 ml for raw sludge, 680 ml for a laboratory-frozen sample of the same sludge and 360 ml for the field-frozen core sample.

Similar results are exhibited for samples F1 and D2 in Figures 65 and 66, respectively. It is concluded that freezing greatly enhanced settleability of sludge and that slower freezing had a more beneficial effect than did fast freezing. Slow freezing allows the growth of large crystals which force the sludge to coagulate and dehydrate. The effect of fast freezing is less coagulation than slow freezing and probably similar dehydration. This is in accordance with the theory proposed by Osterkamp.[20] An analysis of the supernatant from the settleable solids tests from laboratory-frozen sludge indicated BOD, COD and suspended solids concentrations of about ten times that of raw sewage. It is apparent that the drainage water from a fast freeze process will have a much greater effect on a small biological waste treatment plant than drainage water from a slow freeze process. The drainage water is about five times as potent organically as raw domestic sewage and would constitute a shock load to a small biological reactor unless it were trickled in to the head of the plant very slowly.

The results of the drying analysis done on excess sludge samples from the third run, shown in Table 24, are highly questionable due to what appears to be significant sand inclusion. Table 25 contains results of a drying analysis done on an excess sludge sample from the second run. The solids concentrations after laboratory freezing, thawing and 72 hours drying on sand are very high, also due to excessive sand inclusion.

Excess sludge from Run 3 was used in a laboratory freezing experiment, the results of which are shown in Table 26. A small dose of alum (20 mg/l) was introduced to three samples prior to freezing. Three samples were left raw and all six samples were subjected to freezing. Upon thawing, settleable solids tests were performed; the results of these tests are shown in Figures 67-70. Figure 67 indicates that alum enhanced the earlier stages of settleability but showed no improvement after 60 minutes of settling. This observation is in agreement with results found by Clements, Stephenson and Regan.[16] The alum slightly improved the quality of the supernatant but not to an appreciable extent. Figure 68 shows the remarkable effect that freezing had on the settleability of the sludge. Figure 69 indicates that the dosage of alum used produced little additional improvement to settleability after freezing. A family of settleability curves is shown in Figure 70. These curves illustrate the effect of solids concentrations and alum dosage on the settleability of six thawed samples. Alum did not cause the coagulated sludge to be any more compact as it appears to make the final interface height higher for samples of equal total solids concentration. The settleable solids results are likely to be conservative since the thawed sample had to be shaken before commencement of the test. This procedure is likely to disperse and break up the coagulated solids.

Analyses conducted on the supernatant from the settleable solids test indicated BOD concentrations ranging from 1,599 mg/l to 2,088 mg/l and suspended solids concentrations ranging from 74 mg/l to 178 mg/l. The dissolved solids concentrations varied from 2,490 mg/l to 2,832 mg/l. These results indicate a supernatant of approximately six times the strength of raw sewage, in terms of oxygen demand. The suspended solids concentrations are very low suggesting that much of the BOD is exerted by dissolved organic material. The higher BOD and dissolved solids concentration reflect the poorer ice crystal rejection phenomenon when fast freezing rather than slow freezing is utilized.

The effect of increasing alum dosage was not studied in this project. Clements, Stephenson and Regan used a dosage of 200 mg/l[16] while Cheng and Updegraff[26] utilized only 20 mg/l of alum.

E. Summary

To sum up this chapter on discussion of the data it is appropriate to summarize the extensive data into several pertinent observations, enumerated as follows:

1. The sludge used in all three runs was thicker than sludge normally wasted from extended aeration activated sludge treatment plants and therefore would produce slightly conservative results.

2. The raw sludge had very poor settling characteristics; freezing remarkably improved settleability and drainability characteristics of the sludge. Slow freezing as effected in the field was much more beneficial than fast freezing as effected in the laboratory.

3. The mechanism of improved dewatering after a freeze-thaw cycle is a combination of coagulation of sludge, due to the growth of a cellular interface, and dehydration of entrapped sludge particles.

4. Freezing greatly improved the handling characteristics of the sludge. The freeze-treated sludge was granular and earthy in nature as compared to stringy, cohesive raw sludge. The odor of the sludge was reduced by freezing and thawing.

5. The efficiency of freezing, thawing and dewatering sludge is much better for thin sludge in the range of 1.0 - 2.0 percent total solids than for thick sludge, with total solids concentration greater than 2.0 percent.

6. The volume reduction of the sludge as achieved by freezing, thawing and drying in the model beds ranged from 76.7 percent to 90.2 percent of the original volume and averaged 83.1 percent. The volume reductions were greater for thinner sludge, as used in the third run.

7. Neither sludge digestion nor sublimation appeared to be significant processes in the freeze-thaw treatment of sludge in the model beds.

8. The thawed sludge was a good insulator, exhibiting much better insulating properties than raw, freezing sludge.

9. Direct radiant energy from the sun should not be shielded from the beds during the thaw period; more efficient thawing would be effected by exposure thereto.

10. The low temperature driving force and high evaporation rates experienced during the thaw combined to allow much of the

released moisture from the beds to be transferred to the air. It was estimated that all the moisture from the six-inch beds and at least half the moisture released by the 18-inch beds could be handled by evaporation. No flow was ever observed from the perforated drainage pipes installed in the 18-inch beds.

11. Very little site odor was in evidence during any phase of the sludge freezing and thawing program.

12. The separation of clear ice and settled, coagulated sludge solids was observed to be physically distinct in the beds of the third run. The solids in Run 1 and Run 2 were more evenly distributed throughout the vertical extent, except for Bed F, which exhibited about six inches of semi-clear ice at its surface.

13. Sludge could be feasibly removed from the beds before the thaw is fully completed. This would be done by breaking the rotten ice into chunks and hauling it for dewatering to another location. The thawed sludge would be most feasibly removed manually at about 30% solids concentration.

14. The supernatant, or drainage water, from sludge frozen slowly in the field was two to three times the strength of raw domestic sewage with respect to BOD, COD and suspended solids.

15. Rejection of dissolved solids by slow ice crystal growth during freezing would be significant only when good settling takes place before freezing. Then freezing and thawing the "clear" supernatant will result in a considerable lowering of the dissolved solids therein. The importance of this rejection phenomenon in a prototype sludge freeze-treatment unit is questionable. The volume of actual dissolved solids returned to the treatment plant would likely be too low to be of concern. A slight increase in the dissolved solids concentration in a biological waste treatment plant effluent would result.

CHAPTER VII PROPOSED DESIGN, ECONOMICS, ALTERNATIVES

A. General

The design of many extended aeration wastewater treatment plants incorporates sludge holding tanks to which excess sludge may be stored or sand beds on which excess sludge may be dried. Although many investigators[3],[31],[35],[36],[37] point out that sludge wasting is necessary to rid the system of built-up inert polysaccharides and to maintain an active metabolism in the biological reactor, it is rare that routine sludge wasting schedules are followed. Murphy and Grube[38] indicate that auto-sludge wasting occurs at the oxidation ditch serving the University of Alaska partly due to a failure to waste sludge. Chandhuri[7] states that it was originally thought that oxidation ditches could operate without sludge wasting since the accumulation of solids in the system would be negligible as the period of aeration was extended. He indicates that subsequent investigations disproved this belief and demonstrated that non-biodegradable fractions of microbial mass accumulated in the system. Burchinal and Jenkins[39] report on an oxidation ditch operating in West Virginia without using sludge wasting through a two year period even though sand drying beds were provided for this purpose. Solids were washed from the system during high flows. Morris et al.[37] state that plant efficiency for extended aeration treatment plants is directly related to the amount of solids lost as a result of fluctuations in raw waste flow or as a result of denitrification and rising solids in the sedimentation basin and consequent overflow. They suggest that with the addition and use of sludge wasting facilities or effluent-polishing units, these plants would be capable of efficient, continuous operation for long periods of time.

Guillaume[35] suggests that 4,000 mg/l should be the upper limit on the MLSS in an oxidation ditch prior to sludge wasting. Berk[31] suggests that normal operation of an oxidation ditch should allow MLSS to accumulate to 8,000 mg/l in the ditch or to where the dissolved oxygen falls between zero and 0.5 mg/l before sludge wasting should be effected. There appears to be an optimum MLSS level for each plant which would be between 4,000 mg/l and 8,000 mg/l.

McKinney[40] states that there is no easy way to handle waste activated sludge from a conventional plant but that extended aeration sludge can be dewatered directly upon a sand drying bed. He suggests that the period of wasting is a function of the organic load, the size of the aeration tank and the amount of inert solids in the incoming waste. Murphy and Grube[38] state that sludge produced by an oxidation ditch may be air dried for ultimate disposal. Baars[41] contends that oxidation ditch sludge can be dried or kept in storage tanks without producing any bad odor due to fermentation. Clark, Coutts and Christianson[3] suggest that sludge wasting from extended aeration sewage treatment plants is even more important in cold climate operation due to the following reasons:

1. Excess solids production increases with decreasing temperature.
2. Shorter detention times to prevent freezing will also increase solids production at a given MLSS level.
3. Auto-induced sludge wasting may be expected to be more severe, placing greater potential stress on the receiving water.
4. The receiving water has retarded assimilation capacities at cold temperatures.

B. Quantity of Waste Sludge

There is very little literature published regarding the quantity of sludge that should be wasted from an extended aeration, activated sludge treatment plant. To obtain an accurate estimate for a given plant it would be necessary to do an in-plant evaluation in order to determine the coefficients for the classical sludge growth equations.

Baars[41] estimates the excess sludge to be wasted from an oxidation ditch is approximately 30 grams per capita per day. With a population equivalent of about 3,000 contributing to the oxidation ditch observed during this project, the daily sludge solids to be wasted would be 198 pounds on a dry weight basis.

Clark, Coutts and Christianson[3] state that in a cold climate provision should be made for sludge wasting of approximately 0.5 lb. MLSS per lb. of BOD removed. For the plant under observation the amount of sludge to be wasted would be 249 pounds per day. The calculations relating to daily removal are included in Appendix V and utilize data being gathered by Ranganathan and Murphy.[33]

Eckenfelder[42] utilizes a less empirical approach and offers the following equation to estimate the volume of sludge wasting from an extended aeration activated sludge plant.

$$\Delta X_v = 0.23a\ Sr - \text{effluent loss of non-biodegradable residue}$$

where:

ΔX_v = Non-biodegradable residue to be wasted
a = yield coefficient = 0.73 for domestic waste
Sr = BOD removed (lb/day)

He states that in a continuous, completely mixed extended aeration plant with intermittent sludge wasting from the final clarifier, both biodegradable and non-biodegradable sludge will be wasted from the mixture. Therefore, the total wastage will be about double that calculated from the equation above. By using data compiled by Ranganathan and Murphy,[33] the amount of solids to be wasted was calculated to be 145 pounds on a dry weight basis. Assuming an average total solids concentration of 1.5 percent for the wasted sludge and assuming a specific gravity of 1.0 this would represent a daily volume of 155 cubic feet or 1,161 gallons. Calculations pertaining hereto are contained in the Appendix V.

To ensure both a cold climate-oriented and a slightly conservative design the design daily sludge solids to be wasted is estimated to be 249 pounds on a dry weight basis, as recommended by Clark, Coutts and Christianson.[3] Again assuming a specific gravity of 1.0 and an average total solids concentration of 1.5percent, this would represent a volume of 266 cubic feet daily or 1,992 gallons.

C. Proposed Design

For a simple design, relatively free from mechanical intricacies, suitable for small scale operation and amenable to cold weather operation two configurations are suggested, namely:

Sludge drying and freezing lagoons
Sludge drying and freezing sand beds

The ultimate choice of the system would be influenced by the availability of equipment and materials, size and type of sewage treatment plant, and the local physiographic conditions. For the purposes of formulating a hypothetical design it is necessary to state certain criteria:

1. The treatment plant will be of the extended aeration, activated sludge type.
2. The daily raw sewage flow thereto is 300,000 gallons per day.
3. The amount of sludge to be withdrawn daily is 266 cubic feet of 1.5 percent total solids concentration.
4. The climate allows for freezing sludge during the months from October to March, inclusive.
5. The climate is typically interior Alaska-sub Arctic, continental.

1. Sludge Drying and Freezing Lagoons

(a) Literature

Lagoons used for thickening and freezing sludge have been used in

Winnipeg, as reported by Bubbis.[23] Here, 10 inches of completely digested sludge is applied to one of four 20 acre lagoons. The sludge is left 14 days and then decanted. When the lagoon is filled the sludge is removed with heavy equipment scrapers. A ripping and scraping procedure used for the frozen sludge in the winter time. Pescod[43] reports that lagooning is the most common method of sludge dewatering in tropical developing countries. He states that lagoons should be used only for drying and not as ultimate disposal. Fielding[44] contends that lagoons are effective in producing a thickened sludge with up to 50 percent volume reduction but are not effective in producing a dry sludge. He advocates the use of a portable syphon to decant supernatant from sludge lagoons. A floating pipe is used with a hand-operated diaphragm pump to start the system. When the pipe encounters heavy sludge the syphon is automatically broken. He recommends a thickening time of 25 days more than the time required to add the volume of sludge to the lagoons. A consistency of 11 percent total solids is recommended as the maximum for solids which are to be pumped. Four inch diameter polyvinyl chloride (PVC) pipe is used to transport the sludge. The WPCF Manual of Practice for sludge dewatering[45] discusses the design of sludge lagoons. It suggests that warmer arid climates produce the best results for sludge lagoons. Included in the design considerations are recommended placing of the lagoons with respect to dwellings, the possibility of ground water pollution from lagoons, insect breeding problems and fencing. It is recommended that sludge drying lagoons should be constructed with a two foot freeboard and should not be constructed in a marshy area. Depth of sludge in the drying lagoons should not exceed 15 inches. The recommended withdrawal time, if sludge is placed to a depth of 15 inches or less, is from three to five months after application. The wet sludge will not dry enough to be forkable and therefore would have to be removed by mechanical equipment. If the sludge cake is to be used for a fertilizer or soil conditioning purposes it should be stockpiled after removal to allow further drying. Burd[1] reports that lagooning is the most popular sludge disposal technique at industrial wastewater treatment plants. He suggests that lagoons may be natural or artificial depressions in the ground and may be used for either digested or undigested sludge. He further recommends landfilling as an inexpensive ultimate disposal process to follow lagooning. Burd concludes by stating that lagooning of sludge will continue to be popular so long as inexpensive land is available relatively close to the treatment plant site.

B. Design

The proposed design would incorporate two operational phases: summertime drying and wintertime freezing. Two lagoons will be used to provide capacity and storage during the spring thaw and the transitional period in the fall.

The summertime phase would operate from April 1 to September 30. From April 1 to June 1 sludge will be pumped to the lagoons daily and allowed to accumulate to a depth not exceeding 12 inches. Starting June 1 sludge would be pumped to a second lagoon to a depth not exceeding six inches. On October 1 the sludge would be removed from the first lagoon and subjected to final disposal either by landfilling or incineration. This would make this lagoon ready to receive a 12-inches depth of sludge through the period from October 1 to April 1. The six inches of capacity left on the second lagoon would be used to handle fresh sludge during the thaw and dewatering period of the frozen sludge. Each lagoon would be constructed large enough to receive the entire sludge volume wasted for an entire year. This would allow for plant expansion and repairs on one lagoon while the other is receiving fresh sludge. All supernatant would be decanted by means of a portable syphon to the head of the treatment plant. All dewatered sludge would be handled in a landfill or an incinerator, if one were available in the community. If applicable, the dewatered sludge could be used as a soil conditioner.

The dimensioning of the lagoon should ensure as slow freezing as is possible in a workable prototype installation. The final depth of thawed and dewatered sludge will be about three inches.

Dimensions

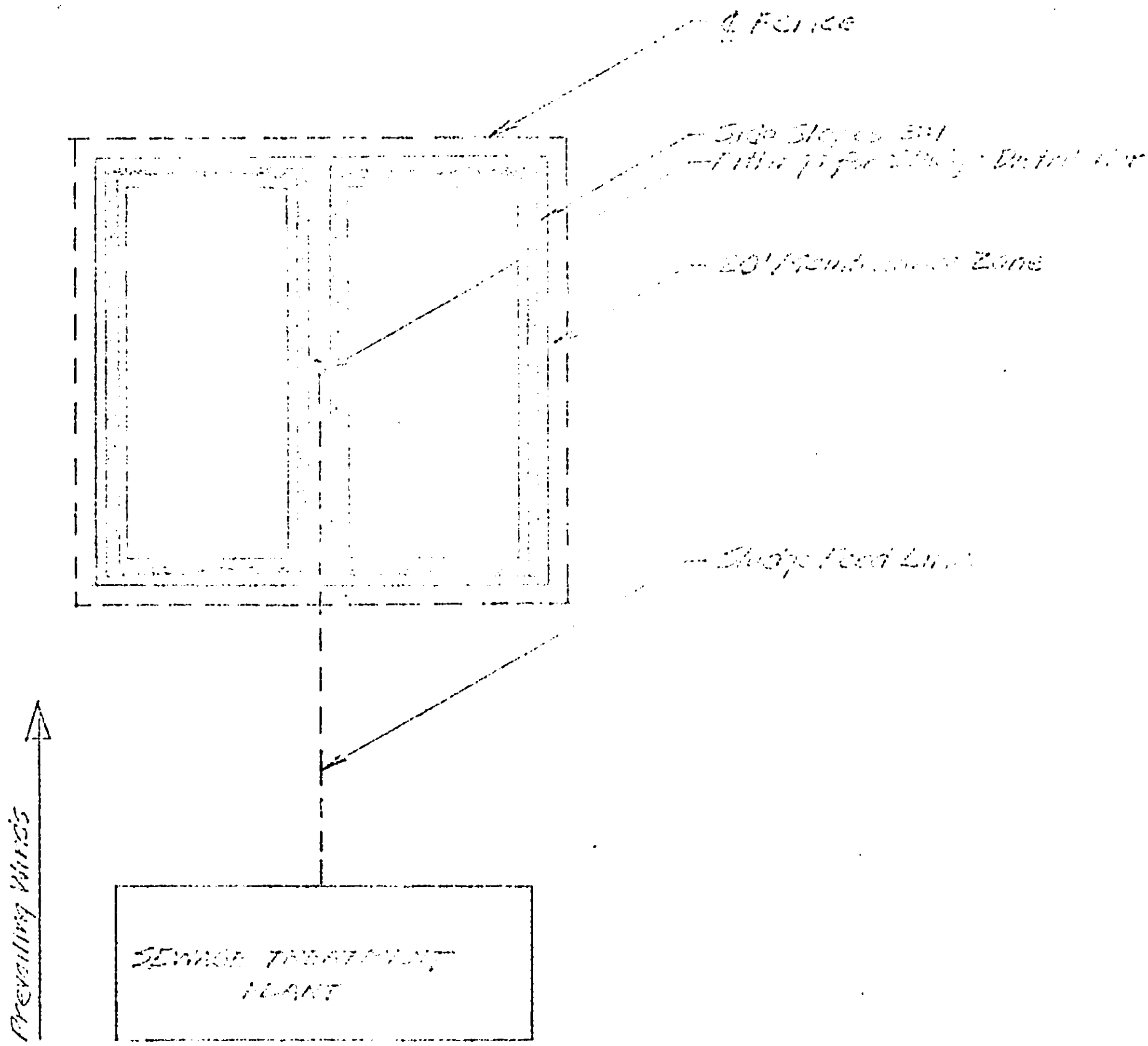
Wasted Sludge volume = 266 x 365
= 97,000 cu ft/year
= 726,530 gal/year
Allowable sludge depth = 12 inches
Required surface area = 97,000 ft^2
Use two rectangular lagoons 220' x 440'
Allow freeboard = 2'
Total depth = 3'
Overall dimensions of each of two lagoons = 440' x 220' x 3'

Details

Use a 4" swing discharge PVC pipe (removable)
Use a 4" PVC pipe in conjunction with a floating siphon to decant the supernatant.
Use a hand-operated diaphragm pipe to operate siphon.
Use available municipal loaders for twice yearly dewatered solids removal.
Surround the lagoons with a six foot chain link fence outfitted with appropriate signs.
If ground water contamination is inevitable line the lagoons with well compacted, impermeable clay or line with an impermeable artificial layer.

A layout of the proposed design is shown in Figure 61. A cost estimate is also included in this chapter.

Figure No. 61– Layout of Proposed Sludge Lagoon



Notes: Use 3' height for berm
[illegible]
Use perforated pipe [illegible] chlorination

Scale: 1" = 200'

2. Sludge Drying and Freezing Sand Beds

(a) Literature

Pescod[43] reports that sand beds are less popular than lagoons for sludge handling in tropical developing countries. He suggests that drainage and evaporation are the major mechanisms for water removal from sludge placed on sand drying beds. Van Kleeck[30] states that the general depth of sludge on drying beds is 8-10 inches. Drainage through the sand is reportedly negligible after the first 24 hours; subsequent drying is due to evaporation. He reports that drying time can be reduced by one-third if alum is used as a pretreatment.

The WPCF Manual of Practice regarding sludge dewatering,[45] outlines design criteria for sand drying. It states that regional climatic conditions greatly affect sludge dewatering on drying beds; the drying time is shorter in regions of greatest sunshine, low rainfall and low humidity. These conditions apply very closely to summertime conditions in the interior of Alaska which include very long periods of sunshine and low humidity. An eight inch layer of digested sludge is reported to be capable of drying to a forkable consistency in two or three weeks. No data is given for dewatering undigested sludge from an extended aeration activated sludge plant.

Burd[1] states that the higher the initial water content of the sludge, the greater is the percentage of water removed by drainage on sand beds. He outlines the effect of solids concentration on drainable water, drainage time and cake moisture content. He states that the "10 States' Standards" and Seelye design criteria for drying bed size recommend 1.75 square feet of sand bed per capita for open beds and 1.35 squarc feet per capita for covered beds. These sizes were applicable for an area between 40° and 45°N latitude. Burd also discusses the effect of chemical pretreatment of sludge, prior to sand drying, or dewatering.

Design

After careful consideration of the literature, it is concluded that sand beds have litle to offer in favor of a lagoon installation for a combined drying and freeze-thaw operation. It is thought, therefore, that a hypothetical design of sand beds is not warranted.

D. Economic Considerations

Table 14 gives an analysis of the expected capital and operating cost of the proposed sludge lagoon design. A comparison of the cost of this design to alternative designs is incorporated in Table 15. The cost data used in constructing these tables were taken from Burd,[(1)] Bubbis,[(23)] Mar,[(46)] and Wheeler.[(47)] It is readily seen that a lagoon installation utilizing optimum summertime drying conditions and the wintertime freeze-conditioning is not only feasible from a logistical viewpoint but also is economical. The cost of ultimate disposal is not included since this would be common to all dewatering processes. It is suggested that ultimate disposal be tied to a joint project with the municipal solid waste disposal program. This could consist of incineration,[(48)] composting[(49),(50)] land-fill,[(1)] or soil conditioning as discussed earlier in Chapter VI. A twice yearly removal of sludge from the lagoon could be effected feasibly with existing municipal equipment in most locations.

In conclusion it is appropriate to quote Mar:[(46)]

> ". . . socio-economic consideration should establish that sludge should receive the maximum degree of treatment technically possible, and that the residue should be discharged to the less sensitive element of the environment. The cost of this activity will be small compared to the total costs of maintaining the environment."

Table 14
COST OF PROPOSED SLUDGE LAGOON

Initial Capital Cost	
Pumps	$ 3,000
Excavation and Berm Construction	8,000
Piping and Fittings	500
Fencing	2,000
Berm Stabilization	1,500
Roadways	1,000
Property	5,000
Engineering and Contingencies	3,000
Miscellaneous Appurtenances	1,000
	$25,000
Annual Operating Cost	
Sludge Pumping	$ 3,600
Supernatant Decanting	800
Sludge Removal	1,900
Maintenance	1,200
	$ 7,500
Unit Costs	
Capital - per ton of sludge	$55
- per capita	8.33
Operating - per ton of sludge	16.50
- per capita per year	2.50
Annual Capital (per capita) (based on 30 year amortization 6% per annum interest)	1.60
Annual per capita overall	4.10
Overall per ton of sludge (same amortization)	48.10

Table 15
COMPARISON OF ESTIMATED COSTS OF VARIOUS ALTERNATIVES

Installation	Per Ton Handled
Lagoons	$48
Vacuum Filtration (with filter aids)	$72
Sand Drying	$115
Centrifugation	$70

E. Design Alternatives

The constraints put on design alternatives for handling sludge from small, cold climate biotreatment plants are extremely restrictive. Several alternatives are outlined and briefly discussed herein.

1. Vacuum Filtration

This method is generally too sophisticated and carries an excessive capital and operating cost for a small treatment plant.

2. Gravity and Pressure Concentration

This system, as described by Goodman and Higgins[51] would be quite adaptable to small cold climate biotreatment plants. It consists of polymer addition and mixing, gravity thickening, and open mesh primary and secondary filters. The filters consist of screens and three sets of compression rollers. The manufacturer estimates one hour attention would be required each day for start-up and shut down, resulting in a low operating cost. Reportedly the concentrator will process 200-500 pounds of dry solids per hour. The operation might be slightly complex and over-designed for small sub-Arctic installations.

3. Sand Bed Drying

As discussed earlier this operation shows little advantage over the lagoon system of drying and freeze-thaw.

4. Electroosmosis

Although this is a compact and potentially attractive unit process, as described by Greyson and Rogers[52] it is too complex for present use in conditioning sludge at small plants.

5. Centrifugation

Centrifugation has showed considerable promise for various industrial processes as reported by Burd.[1] The maintenance costs would be substantial for cold climate operation at small installations.

CHAPTER VIII SUMMARY AND CONCLUSIONS

Specific observations are contained and enumerated in earlier chapters of this thesis; the purpose of the current chapter is to summarize the foregoing chapters and elucidate some general conclusions.

A. Summary

Although the technology of wastewater treatment is well established, lesser attention has been paid to sludge handling and disposal as compared with treatment plant effluent quality control. A totally satisfactory method of sludge treatment and disposal has not yet been developed for small sub-Arctic biological wastewater treatment plants. Field installations utilizing the freeze-thaw method of conditioning sludge are very rare. This project was designed to investigate the feasibility of freeze-thaw conditioning utilizing available natural refrigeration.

The theoretical considerations deal with water purification by freeze-thaw, water treatment plant sludge dewatering and sewage sludge dewatering. Water and sewage effluent purification by the freeze-thaw method is concerned with the rejection of dissolved materials, both organic and inorganic, by the growth of pure ice crystals in a mother liquor. There is no clear distinction between the theories offered for water treatment plant sludge and sewage treatment plant sludge. The mechanism leading to enhanced dewatering after a freeze-thaw cycle appears to involve the following steps:

1. Coagulation of the sludge particles due to the crystal growth of ice.
2. Dehydration of the trapped sludge particles due to freezing.
3. Release of the water upon thawing.

The project consisted of freezing and thawing activated sludge on model sludge drying beds. Samples of raw and frozen sludge were collected and analyzed for a wide range of parameters. Ambient air and sludge temperatures were carefully monitored. Many physical observations were made of the sludge in all phases during an extensive field program. Accepted sanitary engineering techniques were applied to all analyses. Photographs were taken to document physical observations; these are located throughout the body of the thesis.

Extensive data pertaining to raw sludge, frozen sludge cores, field monitoring and miscellaneous experiments are presented in Chapter V. The discussion of the data is contained in Chapter VI.

A hypothetical prototype design consists of a two-celled lagoon, approximately five acres in surface area. An applied sludge depth of one foot would be used inside three-foot berms. The design is relatively simple, suitable for small scale operation and amenable to cold weather operation. It compares very favorably, from an economic viewpoint, to other alternatives for sludge dewatering.

B. General Conclusions

The pertinent general conclusions are outlined as follows:

1. Freezing remarkably improves the settleability and drainability characteristics of raw sludge. Slow freezing is more beneficial than fast freezing.

2. The mechanism of improved dewatering after a freeze-thaw cycle is a combination of coagulation of sludge due to the growth of a cellular interface and dehydration of entrapped sludge particles.

3. Freezing greatly improves the handling characteristics of the sludge. The freeze-treated sludge is granular and earthy in nature as compared to stringy, cohesive raw sludge. The odor of the sludge is reduced by freezing and thawing.

4. The efficiency of freezing, thawing and dewatering is much better for thin sludge in the range of 1.0 to 2.0 percent total solids than for thick sludge, with total solids concentrations greater than 2.0 percent.

5. The volume reduction achieved by freezing, thawing and dewatering sludge averaged 83.1 percent of the original volume of sludge. The average final volume is therefore very close to 1/6 of the original volume.

6. Direct radiant energy from the sun can be efficiently utilized during thawing but would retard freezing, especially during the months of March and October.

7. Sludge could be removed from the beds prior to complete thaw by breaking the rotten ice into chunks and hauling it to a separate dewatering site.

8. The supernatant, or drainage water, from sludge frozen slowly in the field, is two to three times the strength of raw domestic sewage.

9. Slow, one-dimensional freezing of sludge can be assured in the field by utilizing a relatively large surface area and an applied depth of about 12 inches.

CHAPTER IX RECOMMENDATIONS FOR FUTURE RESEARCH

For the pure researcher the following avenues for research on the freeze-thaw process lie open:

A. To establish the effects of freeze-thaw on electrokinetic phenomena or the surface chemistry of sludge.

B. To investigate the upper limit for freezing rate to effect efficient freezing and dewatering.

C. To further investigate the rejection phenomenon by ice crystals as they grow in sludge.

D. To correlate closely the optimum freeze-thaw scheduling with regard to ambient air temperatures.

E. To correlate solids concentration, freezing time and thermal conductivities.

F. To investigate the effect of freezing and thawing on the viability of bacteria and protozoa.

There is also extensive research to be done by the applied researcher in refining the freeze-thaw process for prototype use. Some proposed projects are outlined as follows:

A. To monitor the operation of a model sludge lagoon over a full year's operation as a freezing and dewatering facility.

B. To investigate the results of freezing water treatment plant sludge in the sub-Arctic environment.

C. To further investigate and establish the effect of solids concentration on freezing rates of sludge.

D. To investigate the results of freeze-thaw on sludge drawn from a primary settling tank in a primary treatment plant or a conventional activated sludge plant.

E. To investigate the results of freeze-thaw on conventional activated sludge as opposed to extended aeration sludge.

F. To further investigate the effects of freezing on raw domestic sewage with attention focused on lagooning raw sewage during the wintertime prior to summertime treatment.

LITERATURE CITED

1. Burd, R. S., "A Study of Sludge Handling and Disposal," Federal Water Pollution Control Administration, U.S. Department of the Interior, Publication WP-20-4, 1968.

2. Clark, Sidney E., Coutts, Harold J. and Christianson, Conrad, "Biological Waste Treatment in the Far North," Project No. 1610, Federal Water Quality Administration, Alaska Water Laboratory, College, Alaska.

3. Clark, Sidney E, Coutts, Harold J. and Christianson, Conrad, "Design Considerations for Extended Aeration in Alaska," Federal Water Quality Administration, Alaska Water Laboratory, College, Alaska. Working paper No. 5. July, 1970.

4. Denn, B. and Doe, P. W., "The Disposal of Sludge by the Freezing and Thawing Process," Filtration and Separation, July/August, 1969.

5. American Public Health Association, Standard Methods for the Examination of Water and Wastewater, 12th Edition, New York (1966).

6. Farrell, J. B., Smith, J. E. Jr., et al., "Natural Freezing for Dewatering of Aluminum Hydroxide Sludges," Journal of the American Water Works Association, Vol. 62, No. 12, pp. 787-791, December, 1970.

7. Bishop, Stephen L. and Fulton, George P., "Lagooning and Freezing for Disposal of Water Plant Sludge," Public Works, Vol. 99. No. 6, p. 94, June, 1968.

8. Bardulin, Allen J, Rose, Arthur and Sweeny, Robert F., Wastewater Renovation, Part 1 - Freezing and Gas Hydrate Formation Part 2 - Feasibility Tests of Freezing. U.S. Department of Health, Education and Welfare, Public Health Service AWTR-4 Environmental Health Series, 1963.

9. Anonymous, Summary Report, Advanced Waste Treatment, July, 1964-July, 1967, U.S. Department of the Interior, Federal Water Pollution Control Administration Publication WP-20-AWTR-19.

10. Anonymous, Summary Report, Advanced Waste Treatment Research, January 1962-June, 1964, U.S. Department of Health Education and Welfare, Public Health Service Publication AWTR-14.

11. Applied Science Laboratories, "Purification of Mine Water by Freezing" EPA Water Quality Office, Water Pollution Control Research Series, 14010 DR7, February, 1971.

12. Baker, R. A., "Trace Organic Contamination Concentration by Freezing - I. Low Inorganic Aqueous Solutions," Water Research, Permagon Press, 1967, Vol. 1, pp. 61-77.

13. Katz, William J. and Mason, Donald G., "Freezing Methods Used to Condition Activated Sludge," Water and Sewage Works, Vol. 117, No. 4, p. 110-114, April, 1970.

14. Noda, Soroku, Koyama, Keichi, Takakuwa, Tetsuo and Akutsu, Takeshi, "Experimental Studies on Dewatering of Digested Sludge by Freezing, Thawing and Filtration Method." City Sanitary Engineering Department, Yokahama, Japan, Date unknown.

15. Babbitt, H. E. and Schlenz, H. E., "The Effect of Freezing on Drying of Sludge" University of Illinois Bulletin, December 3, 1929.

16. Clements, G. S., Stephenson, R. J. and Regan, C. J., "Sludge Dewatering by Freezing with Added Chemicals" Inst. Sew. Purif. Part 4, 1950, pp. 318-322.

17. Coackley, P., "Research on Sewage Sludge Carried out in the Civil Engineering Department of University College," Jour. Inst. of Sew. Purif., Part I, pp. 59-72, 1955.

18. Fulton, George P., "New York Community Improves Water Supply System," Water and Sewage Works, Vol. 117, No. 5, pp. 144-147, May, 1970.

19. Balakrishnan, S., Williamson, D. E. and Okey, R. W., "State of the Art Review on Sludge Incineration Practive," Federal Water Quality Administration, U.S. Department of the Interior, WPC Research Series, 17070 DIV, April, 1970.

20. Osterkamp, T.E., "Mechanism of Sludge Dewatering by Freezing," Paper presented at 22nd Alaskan Science Conference, August, 1971, University of Alaska.

21. Wagner, Jan, Notes and Private Communications, December, 1969 - May, 1971, Institute of Water Resources, University of Alaska.

22. Andrews, R. H., "Sludge Treatment and Disposal," OWRC Research Publication, No. 23, January, 1967, Toronto.

23. Bubbis, N. S., "Sludge Drying Lagoons at Winnipeg," Journal of Water Pollution Control Federation, Vol. 34, No. 8., August 1962, pp. 830-832.

24. Bruce, A, Clements, G. S. and Stephenson, R. A., "Further Work of the Sludge Freezing Process," The Surveyor, Vol. 112, p. 849, 1953.

25. Agardy, Franklin J. and Kiado, Michael L., "Effects of Refrigerated Storage in the Characteristics of Waste," Purdue Industrial Waste Conference, 1966.

26. Cheng, Chen-yen and Updegraff, D., "Sludge Dewatering by High Rate Freezing at Small Temperature Differences," Environmental Science and Technology, December, 1970.

27. Nebiker, John H., Sanders, Thomas G. and Adrian, Donald Dean, "An Investigation of Sludge Dewatering," Journal of the Water Pollution Control Federation, Vol. 41, pp. R255-266, August, 1969.

28. Randall, C. W., Turpin, J. K. and King, P. H., "Activated Sludge Dewatering: Factors Affecting Drainability," Journal of the Water Pollution Control Federation, Vol 43, pp. 102-122, January, 1971.

29. Grube, Gareth Alden, "Evaluation of an Oxidation Ditch Activated Sludge Plant in Subarctic Alaska," Masters Thesis, May, 1968, University of Alaska.

30. Van Kleeck, Leroy, "Control of Sludge Quality," Connecticut State Department of Health, 1953.

31. Berk, William L., "Theory, Operation and Cost of the Oxidation Ditch Process," Lake Side Engineering Corporation Chicago, Illinois, 1967.

32. Reed, Sherwood C. and Murphy, R. Sage, "Low Temperature Activated Sludge Settling," Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, 95, No. SA4, August, 1969.

33. Ranganathan, K. R. and Murphy, R. S., Unpublished data, University of Alaska, 1971.

34. Alter, Amos J., "Sewerage and Sewage Disposal in Cold Regions," DA Project IT062112A130, Corps of Engineers, U.S. Army Cold Regions Research and Engineering Laboratory, Cold Regions Science and Engineering Monograph, 111-C5b.

35. Guillaume, F "Evaluation of Oxidation Ditches as a Means of Wastewater Treatment in Ontario," OWRC Publication No. 6, 1964, Toronto.

36. Chandhuri, N. "Technique of Evaluation of System Parameters Relating Solids Accumulation in Oxidation Ditches Process," 5th International WPR Conference, July/August, 1970.

37. Morris, Grover L., et al., "Extended-Aeration Plants and Intermittent Watercourses," U.S. Department of Health, Education and Welfare, Public Health Service, Publication 999-WP-8, 1963.

38. Grube, Gareth A. and Murphy, R. Sage, "Oxidation Ditch Works Well in Sub Arctic Climate," Water and Sewage Works, Vol. 116, No. 7, pp. 267-271, July, 1969.

39. Burchinal, Jerry C. and Jenkins, Charles R., "Ditches Provide Efficient Treatment," Environmental Science and Technology, Vol. 3. No. 11, November, 1969.

40. McKinney, R. E., "Activated Sludge Operational Strategy," EPCS Reports, Vol. 1, No. 2, April, 1970.

41. Baars, J. K., "The Use of Oxidation Ditches for Treatment of Sewage from Small Communities," Bulletin of the World Health Organization, 26, 465-474, 1962.

42. Eckenfelder, W. Wesley Jr., Water Quality Engineering for Practicing Engineers, Barnes and Noble, Inc., New York, 1970.

43. Pescod, H. B., "Sludge Handling and Disposal in Tropical Developing Countries," Journal of the Water Pollution Control Federation, Vol. 43, pp. 555-570, April, 1971.

44. Fielding, M. B., "The Use of Deep Lagoons for Thickening and Drying of Digested Sludge," OWRC Research Publication, No. 12, June, 1966. Toronto.

45. Water Pollution Control Federation, Mannual of Practice No. 20, Sludge Dewatering, 1969.

46. Mar, Brian W., "Sludge Disposal Alternatives - Socio Economic Considerations," Jounal of the Water Pollution Control Federation, Vol. 41, No. 4, p. 547, April, 1969.

47. Wheeler, Robert W., "A Cost Survey of Oxidation Ditches in the United States and Canada," M.S. Problem Report, West Virginia University, 1967.

48. Chow, Ven Te, Handbook of Applied Hydrology, McGraw-Hill Book Company, New York, 1964.

49. Shell, G. L. and Boyd, J. L., "Composting Dewatered Sewage Sludge," U.S. Department of Health, Education and Welfare, Public Health Service, Bureau of Solid Waste Management Publication SW-12C, 1969.

50. Wiley, John S., "A Discussion of Composting of Refuse with Sewage Sludge" American Public Works Association Yearbook, Chicago: 198, 1966.

51. Goodman, Brain L. and Higgins, Robert B., "Concentration of Sludges by Gravity and Pressure," Paper presented at Water Pollution Control Federation Conference, Boston, October 8, 1970.

52. Greyson, J. and Rogers, H.H., "Dewatering Sewage Sludge by Electroosmosis," Presented at 5th International Water Pollution Research Conference, July/August, 1970.

REFERENCES

Alter, Amos J., "Treatment by Freezing," presented at 24th Purdue Industrial Waste Conference Purdue University, Lafayette, Indiana, May 8, 1969.

Baumgartner, D. J., "Water Supply and Waste Disposal Problems at Remote Air Force Sites in Alaska," presented at 11th Alaskan Science Conference, Anchoarge, August 29 - September 2, 1960.

Black, S. A., "Sludge Thickening in Primary Clarifiers," OWRC Research Publication, No. 24, September, 1967, Toronto.

Bubbis, N. S., "Sludge Drying Tests at Winnipeg," Sewage and Industrial Wastes, Vol. 25, No. 11, pp. 1361-1362, November, 1953.

Chalmers, B., "How Water Freezes," Scientific American, Vol. 200, No. 2, pp. 114-122, February, 1959.

Clark, John W. and Viessman, Warren Jr., Water Supply and Pollution Control, International Textbook Company, 3rd Printing, Scranton, Pennsylvania, 1969.

Davis, Robert K., "Some Economics Aspects of Advanced Waste Treatment," Journal of the Water Pollution Control Federation, Vol. 37, pp. 1617-1628, December, 1965.

Day, E. K., "Environmental Sanitation Problems in Alaska and Their Solution," Harvard Public Health Alumni Bulletin, February, 1952.

Dick, R. I., Annual Literature Review, "Sludge Treatment, Disposal and Utilization," Journal of the Water Pollution Control Federation, Vol. 43, June, 1971.

Doe, P. W., Benn, D. and Days, L. R., "Sludge Concentration be Freezing," Water and Sewage Works, Vol. 112, No. 11, pp. 401-406, November, 1965.

Eckenfelder, W. W. and O'Connor, D. J., Biological Waste Treatment, Permagon Press, New York, 1961.

Ehlers, Victor M. and Steel, Ernest W., Municipal and Rural Sanitation, 6th Edition, International Student Edition, Kogakusha Co. Ltd. Tokyo, Japan, 1965.

Fair, Gordon Maskew and Geyer, John Charles, Water Supply and Waste-Water Disposal, John Wiley and Sons, Inc. 6th printing, New York, 1965.

Fair, Gordon Maskew, Geyer, John Charles and Okun, Daniel Alexander, Water and Wastewater Engineering, John Wiley and Sons, Inc., New York, 1968.

Goodman, Brian L. and Foster, William J., "Notes on Activated Sludge," 2nd Edition, Smith and Loveless, Lenexa, Kansas, 1969.

Graefen, H. and Dönges, H. J., "Studies on Parameters Affecting Sludge Dewatering in Pressure Filters," presented at 5th International Water Pollution Research Conference, July/August, 1970.

Gruber, F., "Water Removal from Presedimentation and Filtration Sludge," German Patent. 1,809,772 (June 4, 1970), Chemical Abstracts, Vol. 73, No. 6, p. 28634 r (1970).

Imhoff, Karl and Fair, Gordon M., Sewage Treatment, 2nd Edition, John Wiley and Sons, New York, 1956.

McKinney, R. E., Microbiology for Sanitary Engineers, McGraw-Hill Book Company, New York, 1962.

McKinney, Ross, E. "Overloaded Oxidation Ponds - Two Case Studies," Journal of the Water Pollution Control Federation, Vol. 40, No. 1. pp. 49-56 January, 1968.

Ontario Water Resources Commision, Notes of the Sewage Works Course, Toronto, 1961.

Reed, Sherwood, Notes and private communications, September, 1969, University of Alaska, College, Alaska.

Rowans, P. P., Jenkins, K. H., and Butler, D. W., "Sewage Treatment Construction Costs," Journal of the Water Pollution Control Federation, Vol. 32, No. 6, p. 594, June, 1960.

Rowans, P. P., Jenkins, K. H., and Howells, D. H., "Estimating Sewage Treatment Plant Operation and Maintenance Costs," Journal of the Water Pollution Control Federation, Vol. 35, No. 2, p. 111, Feburary, 1961.

Sawyer, Clair N. and McCarty, Perry L., Chemistry for Sanitary Engineers, 2nd Edition, McGraw-Hill Book Company, New York, 1962.

Wagner, Jan, Notes and private communications, December 1969, University of Alaska, College, Alaska.

Walters, C. F. and Anderegg, J. A., "Water Conservation Through Reuse of Flushing Liquid in an Aerobic Treatment Process," 11th Alaskan Science Conference, August 30, 1960.

Water Pollution Control Federation, Manual of Practice No. 8, Sewage Treatment Plant Design, 1967.

Wood, C. W. and Allanson, J. T., "Dewatering of Sludge," British Patent 1,182,019 (February 25, 1970), Chemical Abstracts, Vol. 72, No. 20 p. 103514 m (1970).

Zeper, J. and DeMan, A., "New Developments in the Design of Activated Sludge Tanks with Low BOD Loadings," 5th International WPR Conference July/August, 1970.

APPENDIX

Appendix I - Tables

Appendix II - Figures

Appendix III - Field Thaw Data

Appendix IV - Evaporation Calculations

Appendix V - Sludge Volume Calculations

APPENDIX I - TABLES

Table 20
CORE ANALYSIS

All results in mg/l except pH and as shown

Supernatant - Water Which Drained Off Thawed Sludge

Sample	pH	Color	BOD	COD	BOD/COD	S.S.	V.S.S.	V.S.S./S.S.	T.S.	T.V.S. % OF T.S.	T.V.S.	REMARKS
$A1_T$	7.00	Yellow	≥2043	3370	-	26	26	100%	N.D.	-	N.D.	
$A1_B$	6.90		≥2043	3820	-	55	55	100%		-		
$A2_T$	7.09		≥2043	5610	-	125	115	92.0%		-		
$A2_M$	7.18		≥2043	2970	-	70	70	100%		-		
$A2_B$	6.98		≥2043	3940	-	92	78	84.8%		-		
$B1_T$	6.87		≥2043	3460	-	24	22	91.7%		-		
$B1_B$	7.11		≥2043	3820	-	68	60	88.3%		-		
$B2_T$	7.08		≥2043	3540	-	46	46	100%		-		
$B2_M$	7.07		≥2043	3640	-	155	135	87.2%		-		
$B2_B$	6.96		≥2043	4180	-	58	54	93.1%		-		
$B3_T$	6.93		2511	3195	0.786	140	104	74.3%		-		
$B3_M$	7.02		≥2589	3195	-	162	126	77.8%		-		
$B3_B$	7.14		2511	3570	0.703	145	120	82.7%		-		
C0-3	7.03		2268	4340	0.523	320	265	82.8%		-		Difficult to get good S.S
C3-6	6.78		2268	9460	0.240	730	600	82.1%		-		sample without disturbir
C6-9	6.72		2268	5440	0.418	370	360	97.3%		-		solids
C9-12	6.54		1932	7490	0.258	1100	760	69.1%		-		
C12-14	6.58		2307	5240	0.441	5280	3700	70.0%		-		
C14-16	6.72		2511	6110	0.411	68	64	94.2%		-		
C16-18	6.63		2571	5680	0.452	284	212	74.7%		-		
C18-21	6.66		2475	7410	0.334	108	92	85.2%		-		

Table 28(Cont'd)
CORE ANALYSES

All results in mg/l except pH and as shown

Supernatant - Water Which Drained Off Thawed Sludge

Sample	pH	Color	BOD	COD	BOD/COD	S.S.	V.S.S.	V.S.S./S.S.	T.S.	T.V.S. % OF T.S.	T.V.S.	REMARKS
$D1_T$	7.27	Yellow	1347	1870	0.720	68	52	76.4%	N.D.	-	N.D.	
$D1_M$	7.27		≥2043	4430	-	150	140	93.3%		-		
$D1_B$	7.15		≥2043	-	-	74	62	83.8%		-		
$D2_T$	7.43		1800	-	-	172	126	73.2%		-		
$D2_M$	7.44		≥2043	3540	-	140	130	92.9%		-		
$D2_B$	7.34		≥2043	3290	-	415	300	72.3%		-		
$E1_T$	7.52		1554	2150	0.724	148	105	71.6%		-		
$E1_M$	7.24		≥2043	4310	-	265	215	81.1%		-		
$E1_B$	7.34		≥2043	-	-	72	60	83.3%		-		
$E2_T$	7.49		996	1830	0.544	255	200	78.4%		-		
$E2_M$	7.16		≥2043	3860	-	160	145	90.6%		-		
$E2_B$	7.18		≥2043	4510	-	145	130	89.6%		-		
$E3_T$	6.94		1704	1960	0.870	122	96	78.6%		-		
$E3_M$	7.12		2319	2980	0.778	785	560	71.3%		-		
$E3_B$	6.84		2550	3625	0.703	228	170	74.6%		-		
F0-2	7.17		39	0	-	130	106	81.4%		-		No odor F 0-6
F2-4	7.80		46	409	0.112	183	109	59.6%		-		
F4-6	8.11		130	0	-	58	24	41.4%		-		I 0 6" very distinct between clear ice & black.
F6-9	7.77		2268	3770	0.602	350	310	88.6%		-		
F9-12	6.52		2268	5360	0.423	510	370	72.6%		-		Ash red F 4-12 and others
F12-15	6.53		≥2346	5280	-	660	550	83.4%		-		
F15-18	6.83		2550	5960	0.428	1046	702	67.1%		-		

Table 28(Cont'd)
CORE ANALYSES

All results in mg/l except pH and as shown

Supernatant - Water Which Drained Off Thawed Sludge

Sample	pH	Color	BOD	COD	BOD/COD	S.S.	V.S.S.	V.S.S./S.S.	T.S.	T.V.S. % OF T.S.	T.V.S.	REMARKS
F18-22	6.92	Yellow	2436	5020	0.484	318	236	74.2%	N.D.	-	N.D.	
$G1_T$	7.23	White	51	157	0.325	13	-	-	222	47.8	106	Diss. Calc.-209 No odor.
$G1_B$	7.04	Yellow	0	2390	0	56	52	92.6%	3476	53.3	1853	Diss. Calc.-3420 Odor.
$H1_T$	7.61	White	51	78	0.654	14	14	100%	72	100%	72	Disc. Calc.-58 No odor.
$H1_M$	7.41	Pale Yellow	168	196	0.857	24	2	8.2%	-	-	-	Odor.
$H1_B$	6.95	Yellow	2037	3109	0.676	228	180	78.9%	4031	62.4%	2517	Diss. Calc.-931 Odor.
$H2_T$	7.89	White-Yellow	246	196	1.25	74	50	67.6%	1411	52.2%	737	Diss. Calc.-1254 No odor.
$H2_B$	6.94	Yellow	2436	3210	0.759	110	78	70.9%	-	-	-	Odor
J0-2	7.34	White	13	0	-	210	114	54.3%	N.D.	-	N.D.	Some quartz like partic
J2-4	6.81	White	6	103	0.582	32	32	100%		-		No odor
J4-7	6.98	White	13	20	0.650	60	32	53.3%		-		No odor

Supernatant From Settleable Solids Test

Sample	pH	Color	BOD	COD	BOD/COD	S.S.	V.S.S.	V.S.S./S.S.	T.S.	T.V.S. % OF T.S.	T.V.S.	REMARKS
C	6.58	Yellow	3020	5090	0.594	250	180	72.0%	N.D.	-	N.D.	These results highly reliable. Solids not disturbed during sampli of supernatant.
F	6.74	Yellow	2443	3280	0.746	110	110	100%		-		
J	N.D.	White	N.D.	N.D.	-	N.D.	-	-		-		

J's data can be taken from slices of cores - very clear. N.D. - Not Done
Samples Stored from sampling date shown until analyses during week of May 17-22 inclusive.
Storage temperature = -18°C Melted at 23 C in lab
Samples were analyzed immediately subsequent to thawing - no storage was effected.

Table 28
CORE ANALYSES

Sample	Dewatered Solids[1] T.S. %	T.V.S. % of T.S.	Remarks	Water - Sludge Mixture[2] T.S.	T.V.S.	TVS/TS %	COD
$A1_T$	11.8	65.3		N.D.	N.D.	-	N.D.
$A1_B$	13.9	63.1				-	
$A2_T$	12.1	67.1				-	
$A2_M$	N.D.	N.D.				-	
$A2_B$	12.2	67.7				-	
$B1_T$	12.7	67.3				-	
$B1_B$	13.4	67.6				-	
$B2_T$	12.8	67.8				-	
$B2_M$	N.D.	N.D.				-	
$B2_B$	13.4	57.1				-	
$B3_T$	14.8	68.3				-	
$B3_M$	N.D.	N.D.				-	
$B3_B$	13.2	67.9				-	
C0-3	10.9	68.6		21989	14754	67.1%	31100
C3-6	12.7	68.1		25696	17554	68.3%	43400
C6-9	14.7	72.4		35800	25632	71.6%	24600
C9-12	15.4	67.7		27048	19024	70.4%	36800
C12-14	11.9	68.9		46240	32448	70.1%	30700
C14-16	16.9	69.2		N.D.	N.D.	-	N.D.
C16-18	N.D.	N.D.				-	
C18-21	16.3	68.3				-	
$D1_T$	11.4	64.3				-	
$D1_M$	N.D.	-				-	
$D1_B$	13.8	64.8				-	
$D2_T$	12.0	64.3				-	
$D2_M$	N.D.	-				-	
$D2_B$	12.0	64.6				-	
$E1_T$	12.6	64.9				-	
$E1_M$	N.D.	-				-	
$E1_B$	11.9	67.3				-	

Table 28(Cont'd)
CORE ANALYSES

	Dewatered Solids[1]			Water - Sludge Mixture[2]			
Sample	T.S. %	T.V.S. % of T.S.	Remarks	T.S.	T.V.S.	TVS/TS %	COD
$E2_T$	10.3	64.9		N.D.	N.D.	-	N.D.
$E2_M$	N.D.	-				-	
$E2_B$	10.5	65.1				-	
$E3_T$	12.8	63.2				-	
$E3_M$	N.D.	-				-	
$E3_B$	14.2	67.0				-	
F0-2	N.D.	N.D.		281	229	81.6%	
F2-4				800	281	35.1%	
F4-6				1005	355	35.3%	
F6-9	16.7	71.1		27360	16897	61.8%	65600
F9-12	15.5	76.2		36586	24471	66.9%	48700
F12-15	19.3	77.1		39429	24994	63.3%	52400
F15-18	14.8	62.9		N.D.	N.D.	-	N.D.
F18-22	15.4	60.4				-	
$G1_T$	N.D.	N.D.				-	
$G1_B$	17.5	47.8				-	
$H1_T$	N.D.	N.D.		N.D.	N.D.	-	N.D.
$H1_M$	N.D.	N.D.				-	
$H1_B$	13.1	59.3				-	
$H2_T$	-	-				-	
$H2_B$	14.9	56.3				-	
J0-2	N.D.	N.D.		630	236	37.4%	0
J2-4				67	-	-	103
J4-7				149	99	66.4%	20
C			Solids used	N.D.	N.D.	N.D.	N.D.
F			in drain-				
J			ability test				

N.D. - Not Done

[1]That left after quickly draining solids on a screen

[2]Mixture resulting from gentle stirring supernatant and dewatered solids (before screening).

Table 23
CORE ANALYSES

Settleable Solids

Time (min)	Interface Height (ml) C	Interface Height (ml) F
0	1000	1000
1/2	920	500
1	855	440
2	770	420
3	635	400
4	602	394
5	581	390
6	565	388
7	560	385
8	550	382
9	541	381
10	540	380
15	534	376
20	515	370
25	510	370
30	505	368
60	491	359
90	481	351

Both samples odorous on thawing.

J has too low solids concentration to show an interface. Some suspended solids fell out within 30 sec. Remainder are colloidal. Some floc probably destroyed during gentle mixing after thaw and before settleable solids test. Actual settleability would be better under completely quiescent conditions.

Sand Drying

Samples C2, E3, H1 (remains thereof) were placed on model sand drying beds (coffee cans with 3" sand and perforated bottom) for 18 hours.

Sample	T.S.	T.V.S.
C2	55.9%	84.9%
E3	41.4%	49.0%*
H1	46.1%	71.4%

*Sand inclusion unavoidable on sampling. Very thin sludge layer.

Drainability (After Babbitt)

615 CC Commercial Sand E.S.=0.5 mm. Unit coeff. 1.44 was placed onto a No. 40 Sieve Tyler Equiv. 35 mesh. One liter of sample was placed on the sand and the filtrate volume was measured with time. Drainability for J is irrelevant.

Time (min)	Filtrate (ml) C	Filtrate (ml) F
0	0	0
1/2	430	565
1	470	574
2	500	578
3	509	580
4	513	582
5	516	583
6	518	584
7	519	584
8	519	585
9	520	585
10	521	593[1]
20	-	-
30	526	596
60	528	596
180	-	596

Sand possibly too coarse - flow thru too fast.

[1] Disturbed sludge for small sample

Remaining sludge on F analyzed for solids T.S. = 21.1%
T.V.S. = 38.9%

Addendum to Table 28
CORE ANALYSES

General Notes

1. Upon thawing solids are black and flocculent, settleable dispersed in nature, i.e. not plastic, cohesive as raw sludge. Solids separation from supernatant is irreversible. Gentle stirring to analyze for water-sludge mixture was followed by separation again. Solids appear to be heavy, dense upon thawing solids remain in a clump and water drains off quickly by gravity. The clumping is dependent on the solids concentration initially.

2. All samples odorous on quick thaw except sample J (all portions) and F 0-6. The "white" samples exhibited no odor. Also no odor in $H2_t$, $H1_t$, $G1_t$.

3. Dewatered solids are black, porous and have obnoxious odor.

4. All BOD's done with no seed.

5. All analyses as per Standard Methods, except drainability.

6. Color of supernatant appears to be largely due to dissolved organic solids. Color of supernatant passed through glass fiber filter is still yellowish where color existed in unfiltered sample. Compare $G1_t$ vs $G1_b$.

7. Gravity draining of water from solids would be enhanced if thawing sample were not contained in a closed atmosphere i.e. a beaker. Water needs a place to go, consider compression zone in settling test. Gravity dewatering is quick initially and slows down with time. It appears that the solids maintain some bound water which will eventually be drawn off by evaporation. Compression of sludge will force more water out.

8. Sand dried samples C2, E3, H1 lost odor as they dried.
   After 18 hours still odorous.
   After 42 hours less odorous.
   After 62 hours negligible, musty odor.

9. Photographs were taken during various stages of thawing.

10. Lab thawing took approximately 4-5 hours.

11. Supernatant color is less intense yellow color for 2nd run samples (D,E,F) than for first run samples (A,B,C). Very little visible suspended matter in supernatant. Color due to colloidal and dissolved solids, likely.

Table 16
DRAINABILITY OF RAW SLUDGE

Time (min)	Volume of Filtrate (ml) 0.81% T.S.	1.23% T.S.	1.80% T.S.	3.19% T.S.	4.26% T.S.
0	0	0	0	0	0
1/2	525	255	105	0	0
1	598	351	188	0	0
1-1/2	-	415	245	0	0
2	656	455	285	1	0
2-1/2	-	502	312	10	0
3	681	515	345	18	0
3-1/2	-	545	372	27	0
4	697	563	403	35	0
4-1/2	-	-	-	39	1
5	705	-	452	41	6
6	711	610	484	49	17
7	712	625	511	60	28
8	713	637	540	71	39
9	714	647	560	82	50
10	715	655	576	93	59
11	-	-	-	104	69
12	-	-	-	115	77
13	-	-	-	125	86
14	-	-	-	134	94
15	715	678	623	143	102
16	-	-	-	152	109
17	-	-	-	161	116

Table 16 (Cont'd)
DRAINABILITY OF RAW SLUDGE

Time (min)	Volume of Filtrate (ml) 0.81% T.S.	1.23% T.S.	1.80% T.S.	3.19% T.S.	4.26% T.S.
18	-	-	-	169	123
19	-	-	-	176	130
20	716	691	647	184	137
21	-	-	-	192	144
22	-	-	-	199	150
23	-	-	-	207	156
24	-	-	-	214	162
25	716	692	653	220	168
30	716	-	-	251	195
35	-	694	662	280	221
40	-	694	662	307	243
45	-	-	-	331	264
50	-	-	-	353	283
55	-	-	-	373	301
60	-	-	-	391	318
65	-	-	-	409	-
70	-	-	-	422	347
75	-	-	-	435	358

Notes:

1. 1,000 ml sludge used for each run.
2. Filtrate generally light yellow in color.

Table 17A
AVERAGE AIR TEMPERATURES-RUN 1

Date	°C
February 12	-15.6
13	-23.4
14	-30.0
15	-20.7
16	-21.9
17	-15.1
18	-16.5
19	-14.5
20	- 6.0
21	- 4.8
22	-10.5
23	-25.1
24	-28.0
25	-30.0
26	-25.5

Table 17B
SLUDGE TEMPERATURES DAILY AVERAGES-RUN 1

Thermocouple Number	Location
1	At centerline of west wall Bed A 3" from sand; 1" from wall.
2	Bed C; Centerline of bed. 1" from sand.
3	Bed C; Centerline of bed. 8" from sand.
4	Bed C; Centerline of bed. 12" from sand.
5	Bed B; Centerline of bed. 1" from sand.
6	Air Temperature*
7	Bed B; at centerline of west wall. 4" from sand; 1" from wall.
8	Bed A; Centerline of bed. 1" from sand.
9	Bed A; Centerline of bed. 5" from sand.
10	Bed A; Centerline of bed. 3" from sand.
11	Bed B; Centerline of bed. 5" from sand.

*Included in Table 17A.

Table 17B (Cont'd)

Date	Thermocouple Number 1	2	3	4	5	7	8	9	10	11
	Temperature -°C									
Feb. 12	7.4	7.4	10.2	+11.7	5.7	3.0	7.4	7.2	8.8	4.7
13	3.4	3.4	4.9	+ 7.5	1.3	+ 1.5	3.4	+ 1.5	2.0	- 1.4
14	+ 0.3	0.3	1.3	+ 3.4	1.0	- 5.6	+ 0.3	- 1.7	+ 0.3	- 5.2
15	- 1.6	- 1.6	- 0.1	+ 1.4	+0.03	- 6.1	- 1.6	- 3.2	- 1.2	- 4.6
16	- 3.5	- 3.5	- 1.4	+ 0.7	- 4.6	- 7.7	- 3.5	- 7.8	- 3.3	- 7.1
17	- 5.3	- 5.3	- 1.7	+ 0.2	- 9.5	-11.7	- 5.3	- 9.8	- 7.6	-13.9
18	- 8.0	- 8.0	- 2.2	- 0.2	-11.3	-12.4	- 8.0	-14.1	-12.9	-13.1
19	- 9.4	- 9.4	- 3.0	- 1.2	-13.0	-13.7	- 9.4	- 9.4	-14.7	-14.4
20	- 6.4	- 6.4	- 2.1	- 0.9	- 9.6	- 8.9	- 6.4	- 9.2	- 9.9	- 9.8
21	- 5.0	- 5.0	- 1.1	- 0.7	- 7.1	- 7.0	- 5.0	- 6.8	- 7.5	- 7.3
22	- 4.8	- 4.8	- 2.4	- 1.4	- 7.4	- 8.3	- 4.8	- 8.5	- 7.9	- 9.2
23	- 9.2	- 9.2	- 7.1	- 4.5	-13.3	-16.1	- 9.2	-18.2	-15.4	-16.5
24	-13.3	-13.3	- 9.6	- 7.1	-18.7	-21.5	-13.3	-20.0	-23.0	-21.7
25	-16.6	-16.6	-12.1	- 9.5	-22.8	-25.0	-16.6	-27.3	-26.0	-24.6

Table 18A
AVERAGE AIR TEMPERATURES-RUN 2

Date		°C
February	27	-15.8
	28	-15.8
March	1	-17.4
	2	-22.3
	3	-27.3
	4	-27.8
	5	-30.6
	6	-30.2
	7	-27.1
	8	-30.0
	9	-30.0
	10	-27.8
	11	-23.4
	12	-21.1
	13	-21.3
	14	-23.5
	15	-18.0
	16	- 2.7
	17	- 4.8
	18	- 7.8

Table 18B
SLUDGE TEMPERATURES DAILY AVERAGES-RUN 2

Thermocouple Number	Location
1	Bed D; Centerline of bed; 1" from sand
2	Bed D; Centerline of bed; 3" from sand
3	Bed D; Centerline of bed; 5" from sand
4	Bed D; Centerline of south wall; 1" from sand; 2" from wall.
5	Bed E; Centerline of bed; 1" from sand
6	Bed E; Centerline of bed; 3" from sand
7	Bed E; Centerline of bed; 5" from sand
8	Bed F; Centerline of bed; 1" from sand
9	Bed F; Centerline of bed; 8" from sand
10	Bed F; Centerline of Bed; 12" from sand
11	Air Temperature - Table 18A

Table 18B (Cont'd)

	Thermocouple Number									
Date	1	2	3	4	5	6	7	8	9	10
	Temperature -°C									
Feb. 27	6.4	6.4	2.1	3.8	3.5	5.2	3.2	6.4	10.0	9.8
28	2.5	2.5	+ 0.2	+ 0.6	1.5	1.4	1.0	2.5	8.1	7.4
March 1	2.0	2.0	- 1.2	- 0.8		+ 0.9	- 1.1	1.6	4.8	3.9
2	+ 1.5	+ 1.5	- 5.4	- 3.2		- 0.8	- 4.0	+ 1.2	2.8	2.1
3	- 3.5	- 3.5	-15.0	-15.8	TOO MUCH SCATTER-READINGS REJECTED	- 9.8	-12.3	- 7.4	+ 1.9	+ 1.7
4	-13.0	-13.0	-22.4	-22.6		-17.7	-19.1	-13.2	+ 1.8	+ 1.3
5	-15.2	-15.2	-26.1	-25.7		-21.3	-22.9	-15.0	+ 1.6	- 0.6
6	-16.2	-16.2	-26.5	-26.6		-23.8	-24.7	-16.3	+ 1.6	- 2.3
7	-15.7	-15.7	-25.8	-25.6		-23.2	-24.4	-15.8	+ 1.3	- 3.1
8	-16.3	-16.3	-26.5	-26.4		-24.3	-25.0	-16.3	+ 0.1	- 4.9
9	-16.8	-16.8	-27.2	-26.6		-25.0	-25.6	-17.0	- 0.9	- 6.0
10	-16.3	-16.3	-25.1	-25.2		-23.5	-24.5	-16.4	- 1.7	- 6.5
11	-14.8	-14.6	-22.3	-23.2		-22.5	-23.0	-14.6	- 2.8	- 6.3
12	-13.8	-13.8	-	-20.9		-20.5	-22.0	-13.8	- 4.0	- 7.3
13	-14.0	-14.0	-	-19.9		-21.7	-	-14.0	- 5.3	- 8.3

Table 19A
AVERAGE AIR TEMPERATURES-RUN 3

Date	°C
March 19	- 4.8
20	- 6.3
21	- 9.3
22	- 8.5
23	- 7.3
24	- 6.8
25	- 9.6
26	-11.2
27	-14.5
28	-12.1
29	-13.3
30	-14.5
31	-13.8
April 1	- 9.7
2	-11.4
3	-13.0
4	- 8.8
5	- 8.6
6	- 8.1
7	-11.1
8	-14.8
9	-14.7
10	-11.1
11	-11.8
12	- 0.7
13	+ 4.2
14	+ 2.6

Notes:

1. Thaw started April 13.
2. See also thaw data April 15, 1971 - June 10, 1971.

Table 19B
AVERAGE AIR TEMPERATURES DURING THAW

Date	°C	Date	°C
April 15	1.6	May 13	8.5
16	2.1	14	7.4
17	3.5	15	6.7
18	1.9	16	5.6
19	- 0.9	17	7.2
20	0.3	18	11.1
21	1.1	19	10.0
22	3.0	20	10.0
23	7.7	21	10.0
24	4.7	22	9.4
25	4.9	23	8.9
26	2.6	24	12.2
27	- 1.0	25	12.8
28	- 0.6	26	11.7
29	0	27	11.7
30	2.2	28	13.3
May 1	2.1	29	11.7
2	4.2	30	11.1
3	4.5	31	14.4
4	4.9	June 1	13.9
5	5.8	2	10.6
6	7.7	3	11.1
7	1.3	4	13.3
8	3.2	5	18.3
9	3.9	6	20.0
10	5.7	7	20.0
11	7.5	8	17.2
12	8.3	9	20.0
		10	22.2

Note: All temperatures positive unless otherwise shown.

Table 19C
SLUDGE TEMPERATURES DAILY AVERAGES-RUN 3

Thermocouple Number	Location
1	Bed G; Centerline of Bed; 1" from sand
2	Bed G; Centerline of Bed; 2" from sand
3	Bed G; Centerline of Bed; 3" from sand
4	Bed G; Centerline of Bed; 4" from sand
6	Bed H; Centerline of Bed; 2" from sand
7	Bed H; Centerline of south wall; 1" from wall; 1" from sand
8	Bed H; Centerline of south wall; 1" from wall; 5" from sand
9	Bed J; Centerline of south wall; 1" from wall; 1" from sand
10	Bed J; Centerline of south wall; 1" from wall; 12" from sand
12	Bed G; Centerline of Bed; 5" from sand
13	Bed G; Centerline of east wall; 1" from wall; 1" from sand
14	Bed G; Centerline of east wall; 1" from wall; 5" from sand
15	Bed H; Centerline of Bed; 3" from sand
16	Bed H; Centerline of Bed; 4" from sand
17	Bed H; Centerline of Bed; 5" from sand
18	Bed J; Centerline of Bed; 1" from sand
19	Bed J; Centerline of Bed; 3" from sand
21	Bed J; Centerline of Bed; 8" from sand
22	Bed J; Centerline of Bed; 12" from sand
23	Bed J; Centerline of Bed; 15" from sand
24	Bed J; Centerline of Bed; 17" from sand

Notes:
1. #11-Air temperature
2. #5-Bed H centerline; 1" from sand inoperative
3. #20-Bed J centerline; 5" from sand inoperative

Table 19C (Cont'd)

Date	1	2	3	4	6	7	8	9	10	12	13	14	15	16	17	18	19	21	22	23	24
	Thermocouple Number / Temperature - °C																				
March 19	4.3	5.4	5.7	5.7	5.3	4.3	4.6	7.7	8.0	5.2	3.9	4.5	5.6	5.6	2.5	5.8	5.0	8.6	7.9	7.9	7.8
20	-0.1	-0.1	0	-0.1	+0.2	-0.4	-2.1	+2.6	+1.9	-0.6	-0.6	-1.8	-0.5	-1.3	-3.9	+2.9	+3.3	+3.4	+2.7	+0.8	-0.8
21	-0.1	-0.2	-0.3	-0.6	-0.1	-0.5	-3.9	+1.0	+0.6	-0.8	-0.7	-3.6	-1.2	-2.4	-7.1	+1.7	+2.0	+2.3	+1.4	-1.3	-3.7
22	-0.2	-0.3	-0.5	-1.6	-0.7	-0.5	-4.6	-0.2	-1.2	-2.5	-1.1	-4.7	-2.1	-3.5	-7.0	+0.8	+0.9	+0.9	+0.2	-2.9	-4.8
23	-0.5	-0.8	-1.7	-3.2	-2.0	-1.2	-5.4	-0.3	-0.6	-4.2	-3.3	-6.3	-3.4	-4.3	-6.1	+0.1	+0.2	+0.1	-0.2	-3.8	-5.4
24	-0.6	-1.4	-2.6	-3.8	-2.6	-2.0	-6.0	-0.6	-0.6	-4.8	-4.8	-7.1	-4.0	-5.0	-7.0	-0.2	-0.2	-0.3	-0.5	-4.7	-6.2
25	-1.2	-2.2	-3.3	-4.5	-3.0	-2.9	-7.0	-0.6	-0.9	-5.8	-6.3	-9.0	-4.5	-5.9	-3.5	-0.4	-0.3	-0.4	-0.5	-6.9	-8.5
26	-2.9	-4.5	-5.4	-6.9	-4.5	-4.9	-9.3	-0.6	-1.3	-8.0	-9.4	-12.0	-6.1	-7.5	-12.6	-0.5	-0.5	-0.5	-1.2	-8.6	-10.2
27	-11.3	-11.8	-12.3	-12.6	-6.5	-7.6	-11.3	-0.6	-2.1	-13.1	-14.9	-14.9	-7.7	-8.4	-11.2	-0.5	-0.5	-0.5	-1.6	-6.3	-7.5
28	-11.8	-11.9	-12.2	-12.6	-10.4	-11.5	-10.8	-0.6	-2.2	-12.7	-12.7	-12.8	-8.6	-8.8	-9.4	-0.5	-0.4	-0.5	-1.5	-7.6	-8.6
29	-12.1	-12.3	-12.6	-12.8	-10.0	-10.4	-12.3	-0.6	-2.3	-13.3	-13.4	-14.4	-10.1	-10.0	-10.0	-0.5	-0.4	-0.5	-1.5	-8.2	-9.0
30	-13.2	-13.5	-13.7	-14.0	-11.5	-11.8	-13.5	-0.6	-2.5	-13.7	-14.4	-15.4	-11.5	-11.4	-11.0	-0.4	-0.4	-0.5	-1.7	-8.6	-10.1
31	-13.8	-14.0	-14.2	-14.3	-12.6	-12.8	-14.0	-0.6	-3.4	-14.4	-14.8	-15.3	-13.0	-13.0	-13.3	-0.5	-0.5	-0.5	-2.3	-9.4	-10.3
April 1	-13.9	-13.8	-13.7	-12.7	-12.7	-13.0	-12.5	-0.7	-3.2	-13.5	-14.0	-13.3	-12.2	-11.7	-10.6	-0.6	-0.6	-0.6	-2.3	-7.7	-8.5
2	-13.4	-13.4	-13.3	-13.0	-12.4	-12.8	-12.6	-0.9	-3.6	-13.2	-13.8	-12.7	-12.5	-14.7	-11.5	-0.8	-0.7	-0.8	-2.7	-8.1	-8.6
3	-10.9	-11.0	-11.0	-11.0	-10.6	-10.9	-11.0	-0.8	-3.0	-11.1	-10.8	-11.0	-10.8	-10.7	-10.7	-0.7	-0.6	-0.8	-2.6	-7.6	-8.3

Table 19C (Cont'd)

Date		Thermocouple Number / Temperature - °C																				
		1	2	3	4	6	7	8	9	10	12	13	14	15	16	17	18	19	21	22	23	24
April	4	-9.3	-9.3	-9.4	-9.2	-9.1	-9.3	-9.7	-0.8	-3.0	-9.6	-9.4	-9.6	-10.0	-9.6	-10.5	-0.7	-0.6	-1.0	-2.8	-7.3	-7.9
	5	NO READINGS																				
	6	-	-	-	-	-	-	-	-0.8	-2.4	-	-7.5	-	-	-	-	-0.6	-0.6	-	-2.3	-5.5	-
	7	-	-	-	-9.3	-	-	-10.7	-	-3.9	-	-	-	-	-	-	-0.7	-0.7	-	-3.6	-	-9.1
	8	-11.3	-	-	-13.1	-	-11.2	-12.7	-0.9	-4.7	-	-	-	-	-	-10.8	-	-0.6	-1.8	-	-	-10.2
	9	-13.5	-	-	-17.0	-	-13.0	-13.6	-1.0	-5.5	-	-	-	-	-	-12.6	-	-0.6	-1.9	-	-	-10.4
	10	-13.7	-	-	-14.5	-	-13.1	-14.4	-1.2	-6.0	-	-	-	-	-	-11.9	-	-0.6	-2.7	-	-	-14.1
	11	-13.7	-	-	-12.9	-	-12.9	-13.0	-1.7	-5.9	-	-	-	-	-	-9.5	-	-0.7	-3.3	-	-	-10.3
	12	-1.7	-1.7	-1.4	-0.9	-1.3	-1.9	+1.7	-1.1	-0.9	-0.7	-1.3	+1.2	-1.1	+3.7	+1.4	-0.7	-0.8	-0.9	-0.8	+1.3	+1.8
	13	-1.4	-1.3	-1.1	-0.7	-1.1	-1.4	+1.3	-1.0	-0.9	-0.7	-1.0	+1.4	-1.0	+1.4	+2.4	-0.7	-0.7	-0.7	-0.6	+1.5	+1.6
	14	-1.1	-0.9	-0.8	-0.4	-0.8	-1.1	+0.8	-0.9	-0.6	-0.4	-0.8	+0.6	-0.7	+0.5	+1.2	-0.7	-0.8	-0.8	-0.7	+0.7	+1.0
	15	-0.8	-0.7	-0.5	-0.3	-0.5	-0.9	+0.3	-0.7	-0.5	-0.2	-0.7	+0.7	-0.4	+0.5	+1.7	-0.6	-0.6	-0.6	-0.5	+0.5	+0.7
	16	-0.9	-0.8	-0.8	-0.7	-0.5	-0.9	+0.6	-0.8	-0.5	-0.5	-0.8	+1.1	-0.6	+1.1	+1.8	-0.7	-0.6	-0.6	-0.5	+1.1	+1.5
	17	-0.7	-0.7	-0.6	-0.3	-0.4	-0.8	+1.7	-0.8	-0.5	+0.8	-0.6	+1.2	-0.3	+2.7	+3.6	-0.7	-0.7	-0.6	-0.5	+2.3	+2.5
	18	-0.7	-0.6	-0.5	-0.3	-0.3	-0.8	X	-0.7	-0.5	X	-0.8	X	X	X	X	-0.7	-0.7	-0.6	-0.5	X	X
	19	-0.6	-0.6	-0.5	-0.2	-0.3	-0.8	X	-0.6	-0.6	X	-0.6	X	X	X	X	-0.7	-0.6	-0.6	-0.5	X	X

Table 19 C (Cont'd)

Date		1	2	3	4	6	7	8	9	10	12	13	14	15	16	17	18	19	21	22	23	24
		Thermocouple Number / Temperature - °C																				
April	20	-0.6	-0.5	-0.6	-0.3	-0.5	-0.8	X	-0.7	-0.6	X	-0.7	X	X	X	X	-0.7	-0.6	-0.6	-0.7	X	X
	21	-0.5	-0.4	-0.5	-0.1	-0.2	-0.3	X	-0.5	-0.6	X	-0.7	X	X	X	X	-0.6	-0.5	-0.5	-0.4	X	X
	22	-0.6	-0.5	-0.5	X	-0.1	-0.7	X	-0.6	-0.8	X	-0.5	X	X	X	X	-0.7	-0.7	-0.7	-0.7	X	X
	23	-0.5	-0.4	-0.4	X	+0.8	-0.7	X	-0.6	-0.5	X	+0.2	X	X	X	X	-0.7	-0.6	-0.6	-0.4	X	X
	24	-0.3	-0.3	+1.7	X	X	-0.4	X	-0.5	-0.2	X	X	X	X	X	X	-0.7	-0.6	-0.5	+0.7	X	X
	25	-0.5	-0.3	X	X	X	-0.5	X	-0.8	-0.2	X	X	X	X	X	X	-0.9	-0.8	-0.8	X	X	X
	26	-0.2	+1.6	X	X	X	-0.4	X	-	+0.9	X	X	X	X	X	X	-0.8	-0.7	-0.6	X	X	X
	27	-0.3	X	X	X	X	-0.5	X	-0.6	X	X	X	X	X	X	X	-0.7	-0.7	-0.6	X	X	X
	28	+0.8	X	X	X	X	-	X	-	X	X	X	X	X	X	X	-	-	-	X	X	X
	29	-0.7	X	X	X	X	-1.0	X	-0.7	X	X	X	X	X	X	X	-0.8	-0.8	-1.2	X	X	X
	30	+1.3	X	X	X	X	-0.6	X	-0.7	X	X	X	X	X	X	X	-0.8	-0.8	-0.9	X	X	X
May	1	X	X	X	X	X	-0.4	X	-0.6	X	X	X	X	X	X	X	-0.8	-0.8	-0.7	X	X	X
	2	X	X	X	X	X	-0.5	X	-0.6	X	X	X	X	X	X	X	-0.9	-0.9	-0.8	X	X	X
	3	X	X	X	X	X	-0.3	X	-0.6	X	X	X	X	X	X	X	-0.8	-0.7	-0.6	X	X	X
	4	X	X	X	X	X	0	X	-0.4	X	X	X	X	X	X	X	-0.6	-0.6	-0.4	X	X	X
	5	X	X	X	X	X	+0.8	X	-0.5	X	X	X	X	X	X	X	-0.7	-0.6	-0.4	X	X	X

Table 19C (Cont'd)

Date		Thermocouple Number / Temperature - °C																				
		1	2	3	4	6	7	8	9	10	12	13	14	15	16	17	18	19	21	22	23	24
May	6	X	X	X	X	X	X	X	-0.5	X	X	X	X	X	X	X	-0.8	-0.8	-0.3	X	X	X
	7	X	X	X	X	X	X	X	-0.5	X	X	X	X	X	X	X	-0.6	-0.6	-0.4	X	X	X
	8	X	X	X	X	X	X	X	-0.4	X	X	X	X	X	X	X	-0.6	-0.5	+0.2	X	X	X
	9	X	X	X	X	X	X	X	-0.4	X	X	X	X	X	X	X	-0.6	-0.5	X	X	X	X
	10	X	X	X	X	X	X	X	-0.4	X	X	X	X	X	X	X	-0.6	-0.5	X	X	X	X
	11	X	X	X	X	X	X	X	-0.4	X	X	X	X	X	X	X	-0.5	-0.5	X	X	X	X
	12	X	X	X	X	X	X	X	-0.4	X	X	X	X	X	X	X	+0.2	+1.0	X	X	X	X
	13	X	X	X	X	X	X	X	+0.2	X	X	X	X	X	X	X	+10.3	+3.0	X	X	X	X
	14	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Notes:

1. Several figures are averaged from only two recorded temperatures. See detailed, unaveraged temperature tables.
2. X-Discontinued

Table 20.
HISTORY OF RELATIVE HUMIDITIES DURING THAW

Date	Air temp.	Relative humidity	Time	Weather
May 6	54°F	44%	3:20 PM	-
7	38°F	75%	5:35 PM	Light snow, breezy
8	44°F	51%	6:20 PM	-
9	51°F	31%	5:40 PM	-
10	55°F	40%	3:10 PM	Sunny, light breeze
11	62°F	28%	3:00 PM	Partly cloudy, very light wind
12	60°F	39%	5:15 PM	Cloudy, brisk wind
13	59°F	29%	5:10 PM	Partly cloudy, light wind
14	57°F	32%	2:00 PM	Sunny, light breeze
15	55°F	49%	4:50 PM	Calm, partly cloudy
16	53°F	53%	4:15 PM	Cloudy, light breeze
17	64°F	22%	6:40 PM	Clear, sunny
18	71°F	36%	4:10 PM	Clear, sunny, light wind
19	67°F	21%	7:30 PM	Partly cloudy, light wind
20	61°F	22%	3:20 PM	Partly cloudy, light wind
21	59°F	38%	6:30 PM	Sunny, windy
22	58°F	37%	3:05 PM	Partly cloudy wind light
23	61°F	31%	12:25 PM	Sunny, calm
24	64°F	41%	3:55 PM	Partly Cloudy, wind light
25	69°F	13%	5:00 PM	Partly Cloudy, wind light
26	69°F	24%	1:45 PM	Clear, light wind
27	64°F	22%	5:00 PM	Clear, light wind
28	66°F	32%	5:00 PM	Cloudy, very light wind
29	62°F	28%	3:30 PM	Partly cloudy, windy
30	63°F	29%	1:20 PM	Calm, partly cloudy
31	70°F	24%	3:00 PM	Light wind, partly cloudy
June 1	55°F	29%	6:50 PM	Cloudy, very windy
2	60°F	10%	11:30 AM	Windy, partly cloudy
Aug	59.7°F	33.2%		

Table 21A
SAMPLES OF THAWED SLUDGE

Collected April 24, 1971

Analyses Commenced April 24, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A		
B		
C		
D		
E		
F		
G	34.7	80.6
H	32.8	81.5
J		

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. Water seems to be tightly bound; minimal dewatering between collection and analysis.
5. Physical Properties - Black, musty odor
   - Appear stable, granular

Table 21B
SAMPLES OF THAWED SLUDGE

Collected April 25, 1971

Analyses Commenced April 25, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A		
•B		
C		
D	19.35	62.2
E	19.45	61.1
F		
G	20.25	59.6
H	16.50	52.9
J		

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. H has thicker melted layer than others; receives the most direct sunlight.
5. Samples contained visible grit-like material.
6. Samples do not readily dewater; water appears to be tightly bound.

Table 21C
SAMPLES OF THAWED SLUDGE

Collected April 26, 1971

Analyses Commenced April 26, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A		
B		
C		
D	20.9	64.6
E	20.5	62.6
F		
G	20.6	59.8
H	18.4	52.6
J		

Notes:
1. Sampling Technique -- with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. No dewatering between sampling and analysis.
5. Samples are soil-like.
6. Musty odor, black color, visible grit.
7. G already 'matting', forkable.
   D, E, H still have no shear strength.

Table 21D
SAMPLES OF THAWED SLUDGE

Collected April 28, 1971

Analyses Commenced April 28, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A		
B		
C		
D	41.7	62.9
E	34.9	61.1
F		
G	23.3	54.8
H	22.4	58.3
J		

Notes:
1. Sampling Technique -- with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. Color grey to black, musty-earthy odor not objectionable.
5. G, H fluffy, forkable mat 1/4 - 1/2 inch thick. These were sampled in the plastic state and are much denser and wetter than D, E.
6. D, E were sampled in more solid state and appear to now have had two freeze-thaw cycles.
7. Grit-like material visible in all samples.
8. No loss of water on any samples between sampling and analysis.

Table 21 E
SAMPLES OF THAWED SLUDGE

Collected May 1, 1971

Analyses Commenced May 1, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A		
B		
C		
D	64.1	61.8
E	49.8	61.9
F		
G	21.6	58.6
H	25.6	53.2
J		

Notes:
1. Sampling Technique -- with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. D, E very thin thawed layer which is very well dried.
5. No loss of water between sampling and drying.
6. Sludge very manageable, appears to be well stabilized.
7. Earthy-musty odor - all samples.

Table 21F
SAMPLES OF THAWED SLUDGE

Collected May 3, 1971

Analyses Commenced May 3, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A	13.9	65.7
B	19.4	65.3
C	17.8	64.7
D	22.0	63.0
E	28.8	55.2
F	11.8	90.0
G	23.7	58.1
H	24.8	53.4
J	15.7	41.9

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. Physical Characteristics - Grey-black color
   Very little odor-earthy, musty
   Consistency resembles peat
5. D, E wetter than May 1 samples due to increased depth of thawed sludge (See Temp. data)
6. E, H only forkable samples prior to analysis
7. A, J have no shear strength. Large floc particles are easily visible. These are the only samples which showed any separation of water and solids between sampling and commencement of analyses.
8. Evidence of grit in all samples.

Table 21G.
SAMPLES OF THAWED SLUDGE

Collected May 5, 1971

Analyses Commenced May 5, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A	26.0	64.9
B	24.0	59.7
C	18.3	63.6
D	25.4	63.7
E	26.3	61.8
F	16.6	62.9
G	21.2	57.2
H	28.4	55.4
J	12.1	47.1

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. Before analyses - D, H forkable
   F quite watery, no shear strength, large flocculent particles
   J very watery
5. All have very little odor - earthy, musty.
6. Hair, grit-like particles most evident in D, E, G, H, the drier samples.
7. Minimal solids-water separation in C, J; none in others.
8. Ash is reddish color; no macro grit; for example, no sand or quartz is visible.
9. All samples have a grey-black color upon collection.

Table 21H.
SAMPLES OF THAWED SLUDGE

Collected May 7, 1971

Analyses Commenced May 7, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A	21.2	64.7
B	25.4	61.0
C	16.8	64.1
D	25.2	62.5
E	25.8	60.8
F	18.3	59.6
G	25.1	57.6
H	34.5	46.8
J	13.2	44.4

Notes:
1. Sampling Technique -- with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. Physical Characteristics - all musty, earthy odor
   all are grey-black color, appear stabilized
   G, H - very dry, moss-like
   A, B - very dense, clay-like plasticity
   D, E - light, would be fluffy if drier.
5. Visible grit in all samples, not the same color or consistency as sludge.
6. No loss of water between sampling and analyses.

Table 21J
SAMPLES OF THAWED SLUDGE

Collected May 10, 1971

Analyses Commenced May 10, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A	23.2	63.3
B	22.5	65.1
C	16.9	63.9
D	34.5	60.3
E	31.7	59.1
F	19.0	58.7
G	31.1	60.4
H	40.6	55.3
Raw	2.14	45.0
J	15.1	45.0
G_f	50.1	55.3
H_f	61.0	52.2

Notes:
1. Sampling Technique - with Spätula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. Physical characteristics same as earlier samples.
5. G_f, H_f - not spatial representation of entire bed; these were taken where sludge was completely thawed to sand.
6. Color of sàmples compared to freshly settled activated sludge. Samples are much darker grey-black.
7. Low volatile portion of raw sample and sample J is likely due to extended drying in water bath before drying at 103° C.

Table 21K
SAMPLES OF THAWED SLUDGE

Collected May 12, 1971

Analyses Commenced May 12, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A	49.1	80.4
B	38.4	63.8
C	32.5	82.3
D	49.3	71.1
E	48.7	70.4
F	34.6	77.3
G	40.4	56.7
H	69.1	83.9
J	29.9	100

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. C, F, J are much denser than others.
5. J malodorous like raw sludge undergoing initial stages of decomposition. Appears to have considerable moisture but unwilling to dewater. Appears as though this sludge was not completely frozen - it does not have the flocculent structure of frozen and thawed sludge; rather it is plastic and cohesive.
6. All samples have a grey-black color.
7. All have earthy-musty odor except J.
8. Evidence of grit in all samples.

Table 21L
SAMPLES OF THAWED SLUDGE

Collected May 13, 1971

Analyses Commenced May 13, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A	24.8	65.8
B	23.8	53.2
C	19.6	68.8
D	50.8	61.0
E	33.4	64.4
F	20.1	61.1
G	47.6	54.6
H	57.2	56.3
J	24.6	57.7
Raw	1.20	50.0

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. Specific gravity of raw sample determined to be 1.03.
5. J very dense, odorous.
6. Other samples quite dry, very little odor.
7. Sample A very dense.
8. Color of samples grey-black; J blacker than others.
9. Sand inclusion is now becoming a possibility especially in G and H.

Table 21M
SAMPLES OF THAWED SLUDGE

Collected May 15, 1971

Analyses Commenced May 15, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A	34.3	63.4
B	37.9	64.9
C	19.5	65.3
D	36.4	62.3
E	31.4	62.5
F	22.2	61.4
G	64.0	56.5
H	57.8	53.8
J	26.2	31.0

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. J appears to have sand inclusion.
5. All have grey-black color, J is blackest and densest.
6. J is the only sample exhibiting noticeable odor - it smells as though it has undergone some decomposition.
7. Vertical sampling position is critical in some samples, especially A, B, D, E - these are wetter at sludge - sand interface. C, F, J are more uniform in their vertical moisture distribution. G, H are very dry throughout.

Table 21N
SAMPLES OF THAWED SLUDGE

Collected May 18, 1971

Analyses Commenced May 18, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A	28.5	62.3
B	36.9	63.6
C	19.5	64.6
D	37.9	60.0
E	32.2	61.3
F	24.7	57.6
G	69.1	54.4
H	78.9	52.8
J	25.3	46.7

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. Volatile portion appears to decrease with extended field drying.
5. Physical characteristics of sludge are as earlier.

Table 21P
SAMPLES OF THAWED SLUDGE

Collected May 20, 1971

Analyses Commenced May 20, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A		
B		
C	31.7	62.8
D		
E		
F	25.2	58.6
G		
H		
J	25.7	45.5

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. Samples taken are wettest field samples.
5. C, F musty odor
   J obnoxious odor - part of sample is cohesive, plastic. This is the portion of the sludge bed which never froze.
6. Sand inclusion is likely in J
7. All have grey-black color.

Table 21Q.
SAMPLES OF THAWED SLUDGE

Collected May 22, 1971

Analyses Commenced May 22, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A		
B		
C	29.1	66.6
D		
E		
F	29.6	52.8
G		
H		
J		

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. Very little odor in both samples.
   Both have grey-black color.
   C is very dense, high specific gravity.
5. Sludge odor decreases as drying progresses.

Table 21R
SAMPLES OF THAWED SLUDGE

Collected May 24, 1971

Analyses Commenced May 24, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A	42.6	60.1
B	46.7	64.5
C	25.4	62.6
D	42.9	59.3
E	49.1	58.8
F	26.1	58.2
G	93.1	55.7
H	84.6	53.4
J	34.7	42.8

Notes:
1. Sampling Technique - with Spätula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. All samples grey-black.
   C, F, J are densest, wettest blackest.
   Others are very dry and low in specific gravity.
5. All samples contain visible grit-like materials, off color.
6. J shows sand inclusion even at top of sample - sand may have been slightly disturbed during sludge pour.
7. Musty odor in all samples, none objectionable.

Table 21S
SAMPLES OF THAWED SLUDGE

Collected May 26, 1971

Analyses Commenced May 26, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A		
B		
C	31.4	63.8
D		
E		
F	33.5	57.9
G		
H		
J	39.5	32.1

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. All grey-black, musty odor.
5. Samples taken are the wettest on site.
6. Sand inclusion in J, even on top of sludge.

Table 21T
SAMPLES OF THAWED SLUDGE

Collected May 28, 1971

Analyses Commenced May 28, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A		
B		
C	29.2	61.1
D		
E		
F	39.4	57.1
G		
H		
J	40.6	39.4

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. J - sand inclusion, even on top.
5. All samples grey-black with musty odor.
6. Visible grit-like material in F, grit remaining in ash of J.
7. No signs of living organisms in any of the samples.
8. These are the wettest samples on site.

Table 21U
SAMPLES OF THAWED SLUDGE

Collected May 30, 1971

Analyses Commenced May 30, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A	59.1	61.6
B	48.3	60.3
C	31.6	62.6
D	43.5	57.6
E	60.9	58.8
F	43.5	57.1
G	91.3	53.1
H	86.3	54.1
J	39.7	42.9

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. Grey-black color.
5. Negligible odor.
6. J has sand inclusions.

Table 21V
SAMPLES OF THAWED SLUDGE

Collected June 2, 1971

Analyses Commenced June 2, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A		
B		
C	35.5	60.9
D		
E		
F	36.8	56.2
G		
H		
J	43.7	59.4

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. Grey-black color, musty odor.
5. J has sand inclusions

Table 21W
SAMPLES OF THAWED SLUDGE

Collected June 5, 1971

Analyses Commenced June 5, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A		
B		
C	39.4	63.0
D		
E		
F	46.7	59.3
G		
H		
J	56.7	43.9

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. C has a very slight odor, others musty.
5. J has sand inclusions.
6. Color grey-black.

Table 21X
SAMPLES OF THAWED SLUDGE

Collected June 9, 1971

Analyses Commenced June 9, 1971

SAMPLE	TOTAL SOLIDS %	TOTAL VOLATILE SOLIDS % of T.S.
A		
B		
C	39.1	61.2
D	73.7	55.8
E		
F	46.3	54.9
G		
H		
J	49.3	47.3

Notes:
1. Sampling Technique - with Spatula taking samples from each quadrant of bed to full depth of thawed sludge layer.
2. All samples dried overnight (about 14 hours) after initial weighing.
3. Time between sampling and initial weighing about 30 minutes.
4. Looks like loss of volatiles from extended field drying.
5. Musty odor; grey-black, blacker where wetter.
6. C has musty odor, others have negligible odor.
7. D, F visible grit, J has sand inclusions.

Table 22.

TOTAL SLUDGE DEPTH IN BEDS (FROZEN PLUS THAWED-INCHES).

Percentage of Original Depth Shown in Second Column, Actual Depth in First Column.

	A		B		C		D		E		F		G		H		J	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
April 15	9-3/8	100%	6-15/16	100%	21-13/16	100%	6-7/16	100%	7-9/16	100%	22-13/16	100%	7-5/8	100%	6	100%	18-3/4	100%
16	9-1/4	98.6	6-11/16	96.4	21-11/16	99.5	6-5/16	98.0	7-9/16	100%	22-11/16	99.5	7-3/8	96.8	5-7/8	97.9	18-1/2	98.6
17	9-5/16	99.4	6-3/4	97.3	21-5/8	99.1	6-5/16	98.0	7-7/16	98.3	22-11/16	99.5	6-5/8	86.8	5-3/4	95.8	18-1/4	97.3
18	9-3/16	97.9	6-5/8	95.5	21-3/8	97.9	6-1/4	97.1	7-7/16	98.3	22-5/8	99.2	6-3/8	83.6	5-3/8	89.5	17-7/8	95.3
19	8-13/16	95.1	6-1/4	90.1	21-1/4	97.4	6-3/16	96.2	7-3/8	97.5	22-1/2	98.6	6-1/4	81.9	5-1/4	87.5	17-7/8	95.3
20	8-13/16	95.1	6-1/4	90.1	21-1/4	97.4	6-1/8	95.1	7-5/16	96.6	22-1/2	98.6	6-1/8	80.3	5-3/16	86.5	17-13/16	94.4
21	8-3/8	89.3	6-1/8	88.2	21-1/8	96.7	5-15/16	92.2	7-3/8	97.5	22-3/8	98.0	5-7/8	77.1	4-15/16	86.5	17-13/16	93.9
22	8-1/8	86.6	5-15/16	85.6	21	96.2	5-15/16	92.2	7-1/16	93.4	22-3/8	98.0	5-5/8	73.8	4-13/16	80.2	17-/16	91.6
23	8	85.3	5-15/16	85.6	20-7/8	95.8	5-3/4	89.3	6-15/16	91.6	22-3/16	97.2	5-7/16	71.3	4-5/8	77.1	17	90.6
24	7-7/8	84.0	5-5/8	81.1	20-1/2	93.9	5-7/16	85.5	6-11/16	87.2	21-15/16	96.0	5-1/16	66.3	4-3/8	72.9	16-5/8	88.7
25	7-13/16	83.3	5-3/16	74.8	20-1/8	91.7	5-5/16	82.5	6-1/2	85.9	21-7/16	94.0	4-7/8	63.9	4-5/16	71.9	16-5/16	86.0
26	7-5/16	78.0	5-3/16	74.8	19-7/8	91.0	5-1/8	79.6	6-3/8	84.3	21-7/16	94.0	4-7/16	58.2	4-1/8	68.5	16	85.3
27	7-5/16	78.0	5-1/8	73.9	19-7/8	91.0	5-1/16	78.5	6-1/4	82.6	21-1/4	93.0	4-1/4	55.7	3-3/8	56.3	15-15/16	85.0
28	7-1/8	75.8	4-7/8	70.3	19-11/16	90.2	5-1/16	78.5	6-1/8	81.0	21-3/16	92.7	4-1/8	54.1	3-1/4	54.2	15-7/8	84.6
29	7-1/8	75.8	4-7/8	70.3	19-5/8	90.0	4-15/16	76.7	6	79.3	21-3/16	92.7	4-1/8	54.1	3-1/4	54.2	15-3/4	83.9
30	7-1/8	75.8	4-13/16	69.4	19-1/2	89.3	4-15/16	76.7	5-15/16	78.6	21-1/16	92.0	4-1/8	54.1	3-1/4	54.2	15-3/4	83.9
May 1	7-1/16	74.8	4-3/4	68.5	19-7/16	89.1	4-15/16	76.7	5-15/16	78.6	21-1/16	92.0	4-1/8	54.1	3-1/4	54.2	15-3/8	81.9
2	6-11/16	71.3	4-9/16	65.8	19-3/8	88.8	4-15/16	76.7	5-15/16	78.6	20 9/16	90.0	3 11/16	48.3	3-3/16	53.1	14-15/16	79.6
3	6	63.9	4	57.6	18-7/16	88.6	4-3/4	73.8	5-15.16	78.6	18-7/8	82.7	3-3/16	41.8	3-1/16	51.1	14-7/16	76.9

Table 22. Continued.

		A		B		C		D		E		F		G		H		J	
		1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
	4	5-15/16	63.3	3-13/16	54.9	18-1/16	82.7	4-3/4	73.8	5-7/8	77.7	18-1/2	81.1	2-7/8	37.7	2-13/16	46.9	14-1/4	76.0
	5	5-7/16	59.9	3-7/16	49.6	18-1/16	82.7	4-5/16	66.9	5-3/4	76.0	17-7/8	78.3	2-9/16	33.6	2-7/16	40.6	13-3/4	73.3
	6	4-3/8	46.6	2-15/16	42.3	17-13/16	81.6	4-3/16	65.1	5-3/8	71.0	17-1/4	75.6	1-3/4	22.9	1-11/16	28.1	13/1/16	69.6
	7	4-3/8	46.6	3	43.2	17-5/16	79.3	3-15/16	61.2	5-1/8	67.8	16-11/16	73.1	1-5/8	21.3	1-13/16	30.2	12-5/8	67.3
	8	4-1/4	45.3	2-13/16	40.6	17-5/16	79.3	3-7/8	60.2	5-1/8	67.8	16-11/16	73.1	1-1/2	19.7	1-1/4	20.8	12-1/2	66.6
	9	4-1/8	44.0	2-3/4	39.6	16-3/4	76.7	3-3/4	57.2	4-11/16	62.0	16-9/16	72.5	1-1/2	19.7	1-1/4	20.8	11-5/16	60.3
	10	4	42.6	2-1/2	36.0	16-3/4	76.7	3-3/4	57.2	4-9/16	60.3	16-1/4	71.2	1-1/2	19.7	1-1/4	20.8	11-1/2	61.3
	11	3-7/16	37.6	2-3/8	34.2	16-1/16	73.6	3-9/16	55.4	4-5/16	57.1	15-11/16	68.7	1-1/2	19.7	1-1/4	20.8	10-7/8	58.0
	12	3	32.	2-7/16	35.1	15-7/16	70.7	3	46.6	3-9/16	47.2	15	65.6	1-3/8	18.0	1-1/4	20.8	9-9/16	51.1
	13	2-3/8	25.3	2-3/8	34.2	14-1/2	66.4	2-5/16	35.9	2-7/8	38.0	14 3/16	62.2	1-1/2	19.7	1-1/2	25.0	10-13/16	57.7
	14	2-1/4	24	2-1/4	32.4	14-1/2	66.4	2-1/8	33.0	2-7/8	38.0	13-7/8	60.8	1-1/2	19.7	1-1/2	25.0	10-1/2	56.0
	15	1-3/4	18.7	1-7/8	27.0	13-7/16	61.5	1-7/8	29.2	2-1/8	28.1	13-7/8	60.8	1-1/2	19.7	1-1/2	25.0	9-1/2	50.7
	16	1-3.4	18.7	1-3/4	25.2	13	59.6	1-3/4	27.2	1-7/8	24.8	13-11/16	59.9	1-1/2	19.7	1-5/16	21.9	7-11/16	40.9
	18	1-3/4	18.7	1-3/4	25.2	10-1/2	48.1	3-3/4	27.2	1-7/8	24.8	11-5/16	49.6	1-3/8	18.0	7/8	14.6	3-1/8	16.7
	20	1-3/4	18.7	1-3/4	25.2	9-1/4	42.4	1-3/4	27.2	1-3/4	23.2	11-11/16	51.1	1-1/8	14.8	7/8	14.6	3	16.0
	22	1-3/4	18.7	1-3/4	25.2	7-15/16	36.4	1-3/4	27.2	1-3/4	23.2	10-5/8	46.5	1	13.1	7/8	14.6	3	16.0
	24	1-5/8	17.3	1-3/4	25.2	6-13/16	31.2	1-1/2	23.3	1-5/8	21.5	10-1/16	44.1	1	13.1	7/8	14.6	3	16.0
	26	1-3/4	18.7	1-5/8	23.4	6-3/16	28.4	1.1/2	23.3	1-5/8	21.5	7-1/16	31	7/8	11.5	7/8	14.6	3	16.0
	28	1-3/4	18.7	1-5/8	23.4	6-1/4	28.6	1-1/2	23.3	1-5/8	21.5	6-7/8	30.1	7/8	11.5	7/8	14.6	3	16.0
	30	1-3/4	18.7	1-5/8	23.4	6-1/4	28.6	1-1/2	23.3	1-5/8	21.5	6-7/8	30.1	7/8	11.5	7/8	14.6	3	16.0
June	2	1-3/4	18.7	1-5/8	23.4	5-1/8	23.5	1-1/2	23.3	1-1/2	19.8	5-1/4	23.0	3/4	9.8	3/4	12.5	3	16.0
	5	1-3/4	18.7	1-5/8	23.4	4-1/8	18.9	1-1/2	23.3	1-1/2	19.8	3-3/4	16.4	3/4	9.8	3/4	12.5	2-1/4	12.0
	9	1-3/4	18.7	1-5/8	23.4	4	18.3	1-1/2	23.3	1-1/2	19.8	3-1/2	15.3	3/4	9.8	3/4	12.5	2	10.7

Table 23
LABORATORY FREEZING STUDY-RUN 2

Sample	Supernatant from Settleable Solids Test					Settled Sludge from Settleable Solids Test	
	BOD mg/l	COD mg/l	BOD/COD	S.S. mg/l	pH	T.S. %	T.V.S. % of T.S.
F2	4044	5000	0.809	2840	6.42	20.2	-
F1	3912	4640	0.803	2920	6.43	27.3	58.7
D2	3780	5400	0.701	2800	6.42	13.7	83.4

Settleable Solids

F2 t	F2 h	F1 t	F1 h	D2 t	D2 h
0	1000	0	1000	0	1000
1 min	990	1 min	980	2 min	968
3	970	7	957	6	912
9	950	9	938	9	900
12	945	13	910	17	835
14	920	15	862	24	780
16	902	18	832	28	760
20	868	26	765	31	745
23	847	32	720	39	707
31	790	36	703	42	703
38	749	39	692	46	695
42	731	47	671	50	686
45	721	50	664	60	677
53	696	54	660	1.15hr	656
56 min	681	58	652	1.27	651
1.07hr	673	1.13hr	640	1.43	642
1.23	657	1.28	632	1.67	635
1.35	649	1.40	629	1.73	631
1.47	641	1.57	622	3.88	602
1.63	632	1.80	616	4.63	600
1.87	628	1.90	612	16.77	582
1.97	621	4.03	591	17.46	582
4.17	595	4.80	590		
4.86	590	16.88	572		
16.94	571	17.63	572		
17.69	571				

t = time
h = height of interface (ml)

Notes:
1. Odor on thawing
2. Sludge frozen 48 hrs. at -17°C
3. Excellent dewatering on sand.

Table 24.
DRYING EXPERIMENT - RUN 3 RAW SLUDGE

Sample	T.S.(%)	T.V.S. (% of T.S.)
H1	83.4	Rejected*
G1	80.4	10.64%
G2	82.1	41.7%

*Very high sand inclusion

Note:

1. Raw sludge dried 24 hours on sand at room temperature 25°C.
2. Sludge didn't shrink or dry as well as sludge which was laboratory-frozen after Run 2.

Table 25.
DRYING EXPERIMENT-LABORATORY-FROZEN SLUDGE - RUN 2.

Sample	T.S.(%)	COD mg/g
F2	79.9	191
F1	82.4	308
D2	80.9	280

Notes:

1. Sludge frozen at -17°C in laboratory, thawed at 25°C, poured on sand in coffee cans and dried for three days.
2. BOD of dried sludge was undetermined since no depletion was seen in dissolved oxygen. No seed was used.
3. Too much sand inclusion to do T.V.S.
4. To determine COD of dried sludge a small aliquot was mixed with distilled water in a waring blender.

Table 26.
LAB-FREEZING EXPERIMENT WITH ALUM-RUN 3 SLUDGE SETTLEABLE SOLIDS

Sample No Alum.	Time (min.) 0	1	2	3	4	5	6	7	8	9	10	15	20	25	30	60	120
G1	1000	980	740	690	660	630	600	580	570	560	550	540	520	514	510	480	450
J1	1000	980	720	680	670	640	610	590	580	570	560	540	530	522	520	510	490
J2	1000	960	780	730	680	640	610	590	570	550	540	510	490	490	484	460	430
Alum.																	
G2	1000	790	690	624	580	550	540	530	520	510	504	500	490	484	480	470	460
H1	1000	880	810	790	740	730	710	690	670	660	650	630	610	606	606	590	570
H2	1000	844	770	710	670	640	620	610	600	600	590	570	564	560	560	540	520

SUPERNATANT ANALYSIS

Sample	pH	COD mg/l	BOD mg/l	T.S. mg/l	T.V.S. % of T.S.	S.S. mg/l	V.S.S. % of S.S.	Diss. solids mg/l (Calc.)
No Alum								
G1	6.71	≥685	1704	2668	66.4	154	75.2	2514
J1	6.80	≥1370	1848	2598	60.0	108	79.6	2490
J2	6.74	≥1370	2088	2810	61.0	178	79.7	2632
Alum								
G2	6.82	≥1370	1809	2734	65.2	74	81.1	2660
H1	6.69	≥1370	1878	2826	65.6	130	78.5	2696
H2	6.71	≥1370	1599	2914	65.8	82	85.4	2832

Notes:
1. Alum dosage 20 mg/l of sludge
2. No seed used for BOD's
3. Necessary mixing before settleable solids test would break floc.
4. Freezing at -17°C; thawing at 25°C
5. Obnoxious odor on thawing
6. Supernatant yellow, colloidal.

Table 27.
DRAINABILITY OF LABORATORY FROZEN SLUDGE

Time (min.)	Volume of Filtrate (ml)	
	3.19% T.S.	4.26% T.S.
0	0	0
1/2	500	410
1	555	460
1-1/2	565	470
2	575	480
2-1/2	578	482
3	580	485
3-1/2	581	487
4	583	489
4-1/2	584	490
5	584	490
6	585	492
7	585	494
8	585	495
9	586	496
10	586	497
15	588	503
20	589	504
25	590	506
30	591	507
35	592	508
40	593	509
45	593	509

Notes:

1. 1000 ml sludge pored onto 615 c.c sand in No. 40 sieve.
2. Sludge forzen at -17°C, thawed at 25°C, gently stirred before pouring.
3. Thawed sludge has large pieces of coagulated solids.
4. Sludge left on sand dries much more quickly than unfrozen sludge.

APPENDIX II - FIGURES

Figure No. 60A - Settleable Solids - Core Samples

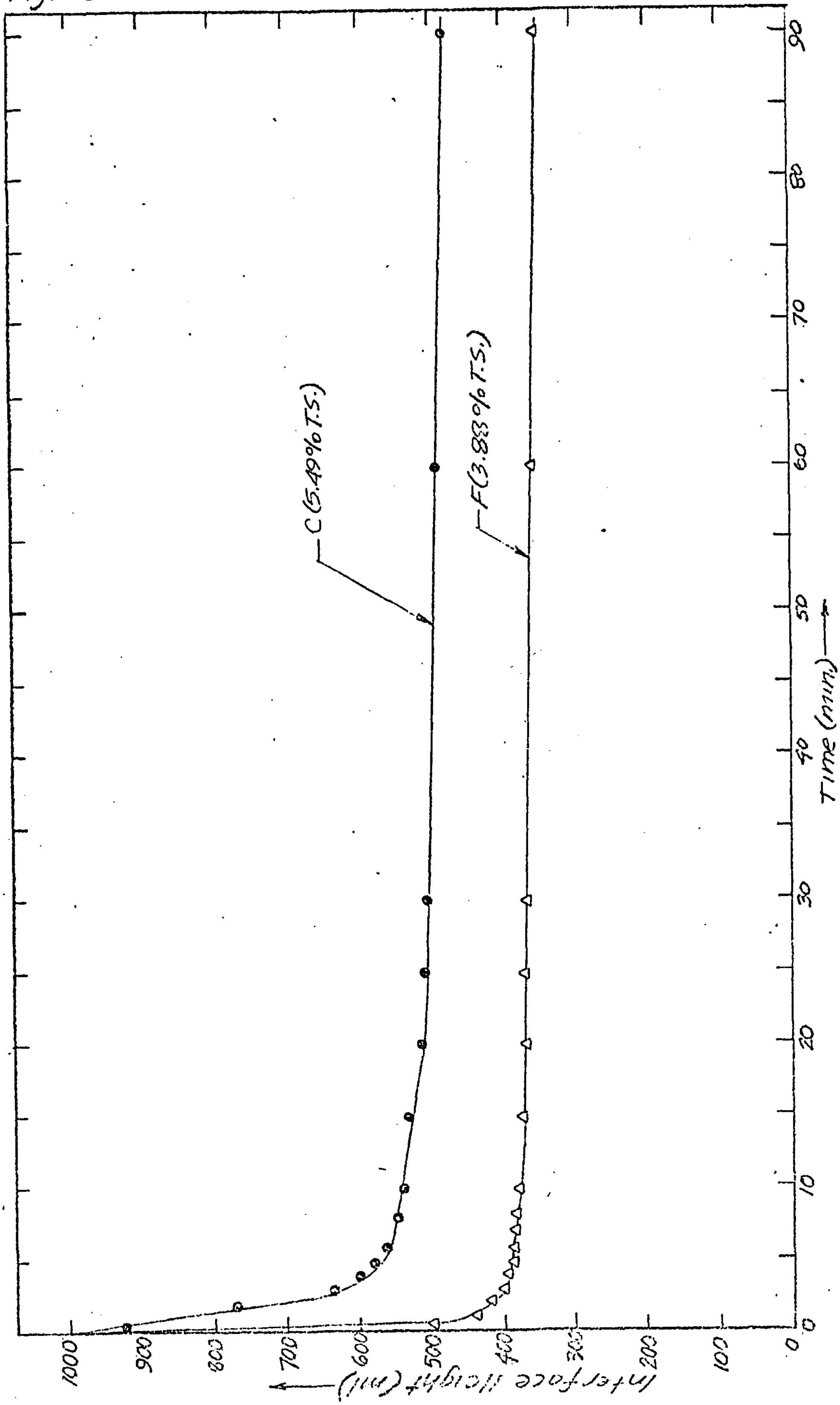


Figure 60B Core Analyses - Sample A2

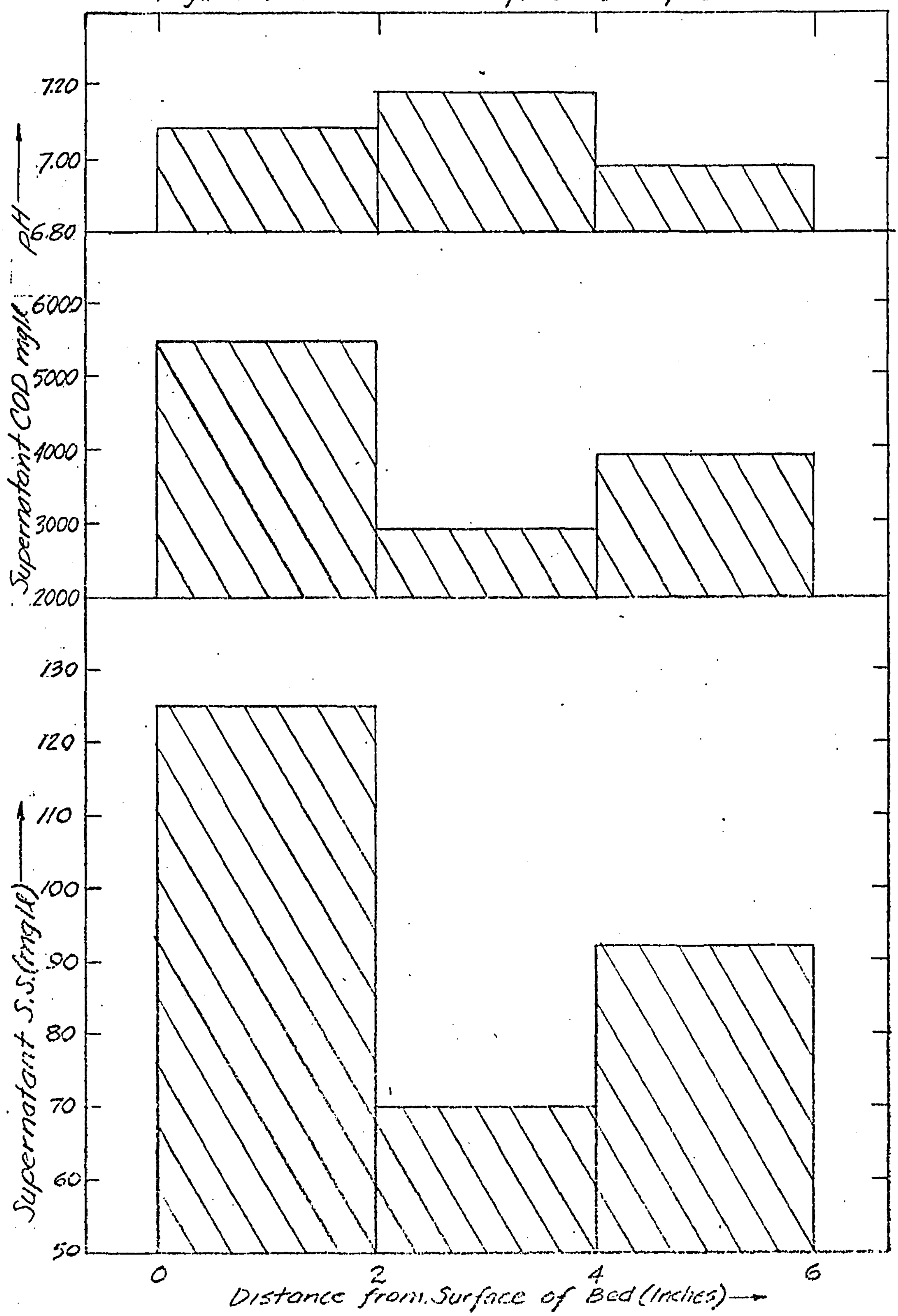


Figure 60C Core Analyses - Sample B2

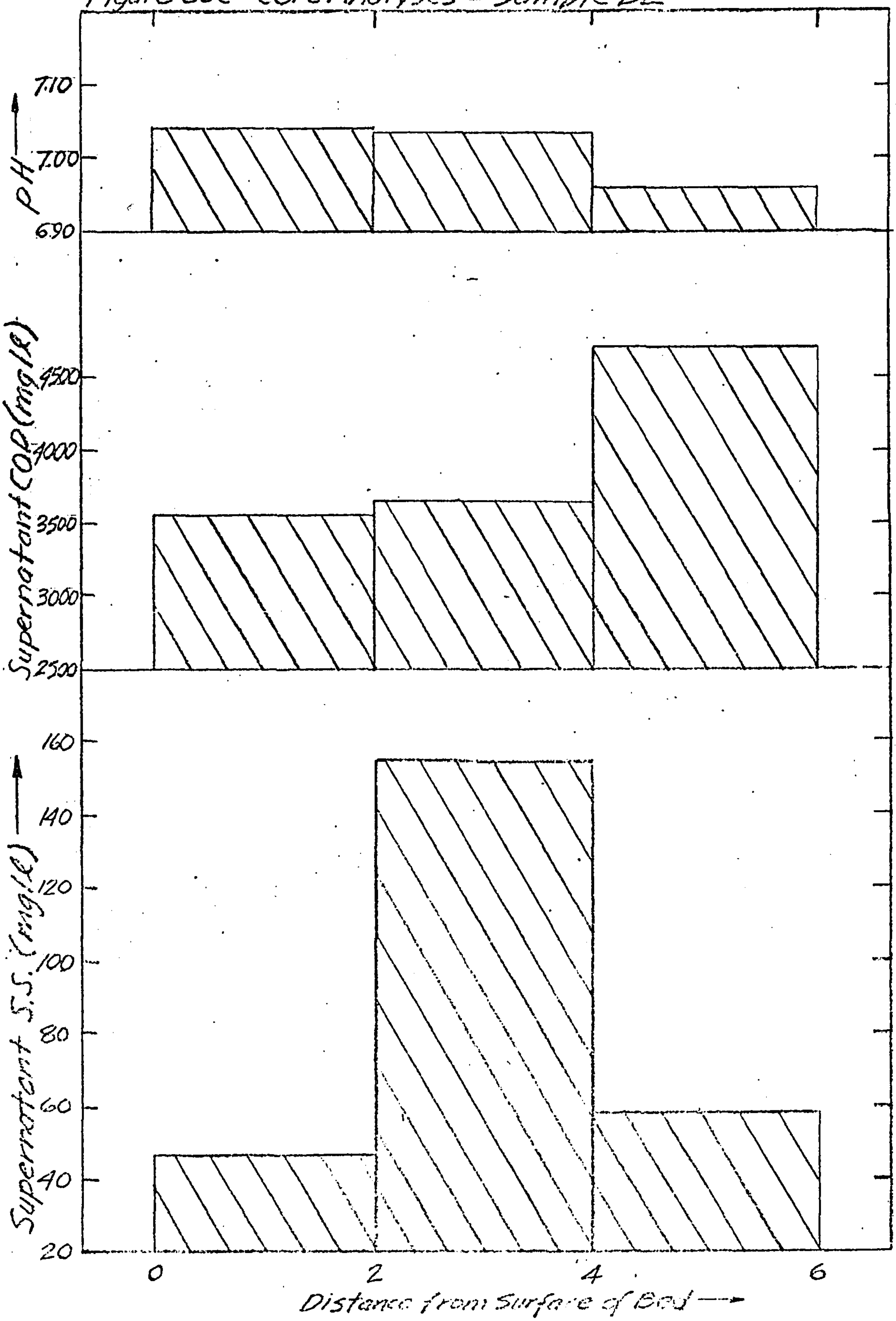
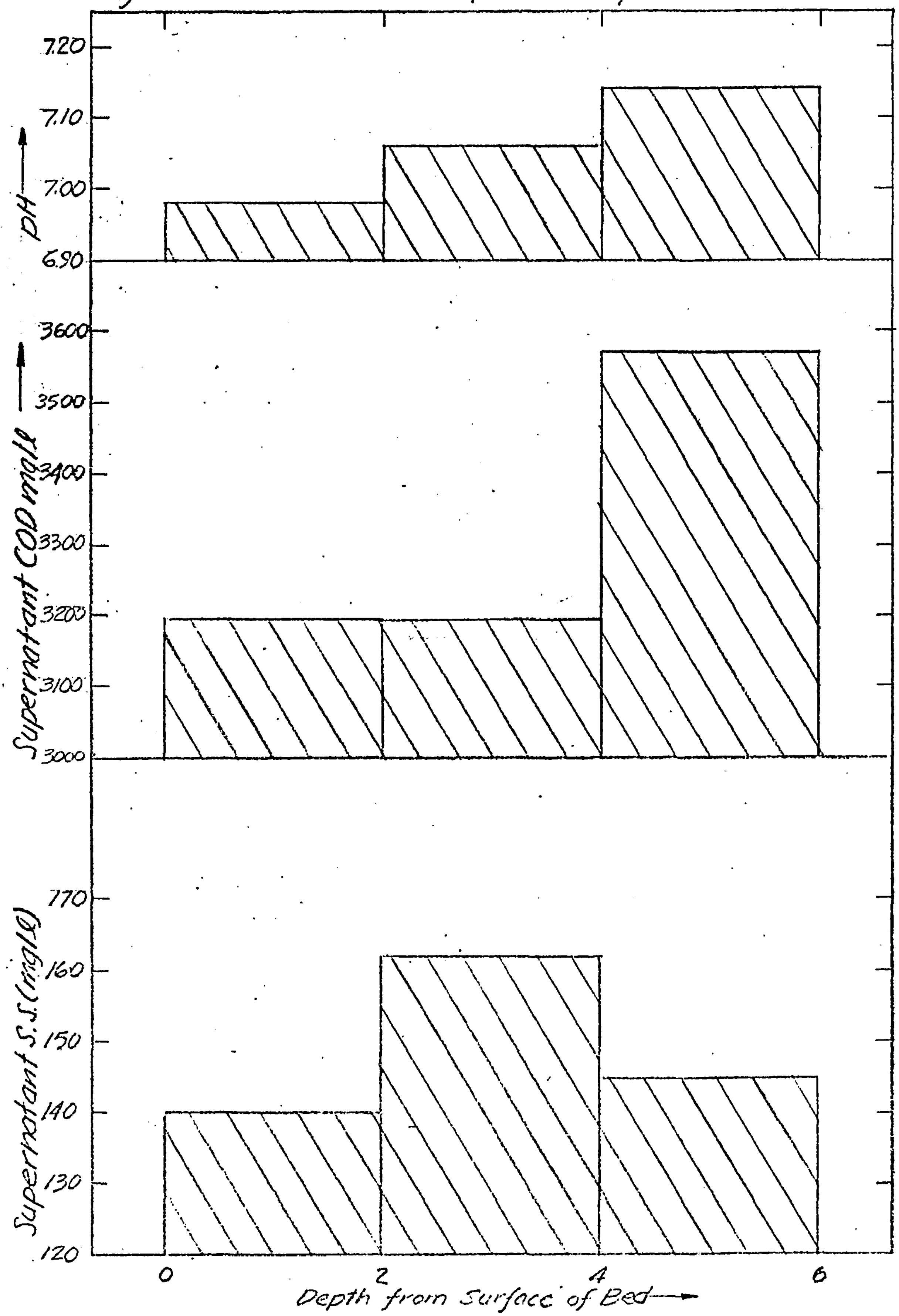


Figure No 60D Core Analysis – Sample B3



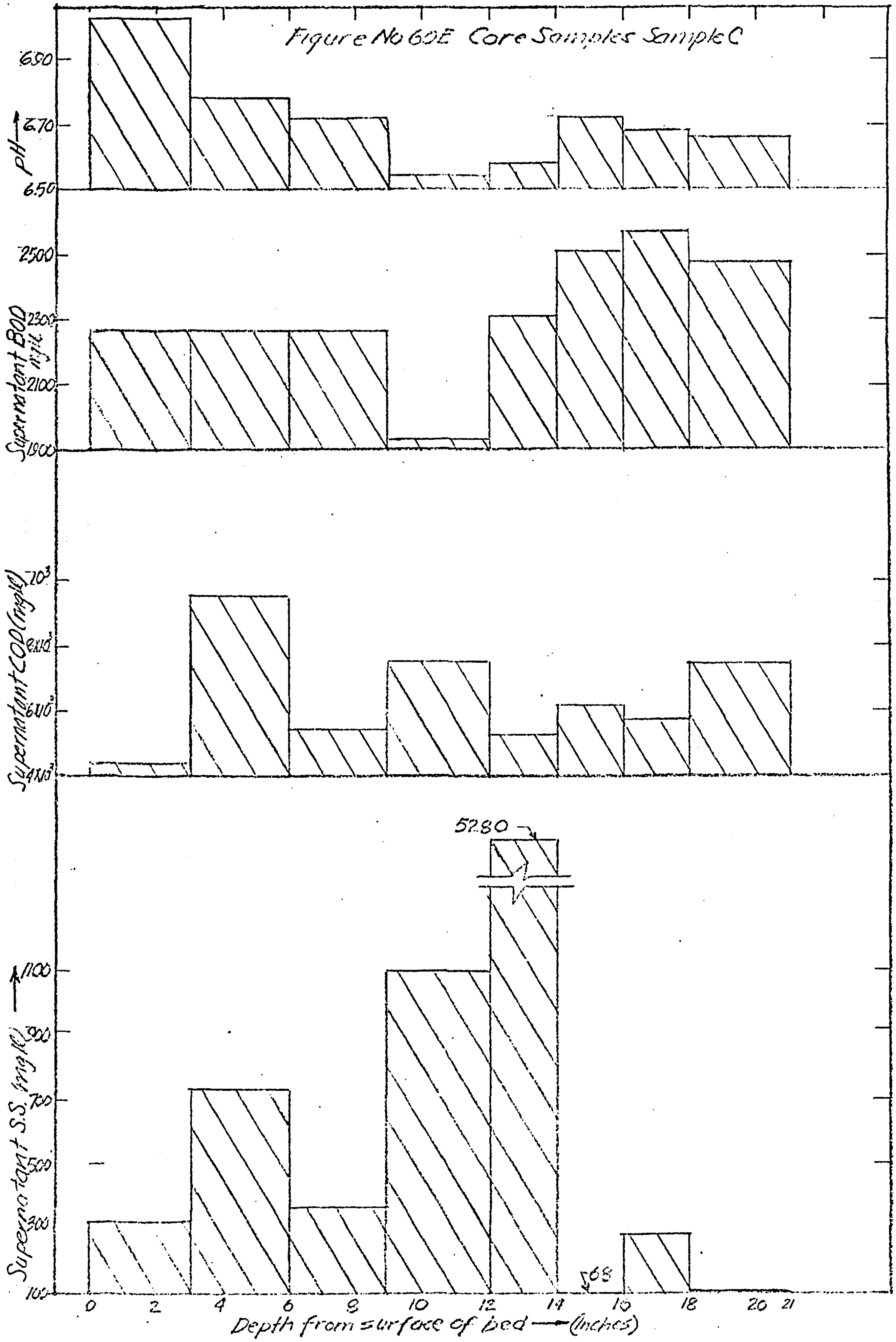


Figure No 60E Core Samples Sample C
pH
6.90
6.70
6.50
Supernatant BOD mg/l
2500
2300
2100
1900
Supernatant COD (mg/l)
10^3
8×10^3
6×10^3
4×10^3
Supernatant S.S. (mg/l)
5280
1100
900
700
500
300
100
68
0
2
4
6
8
10
12
14
16
18
20
21
Depth from surface of bed (inches)

Figure 60F Core Analyses - Sample D1

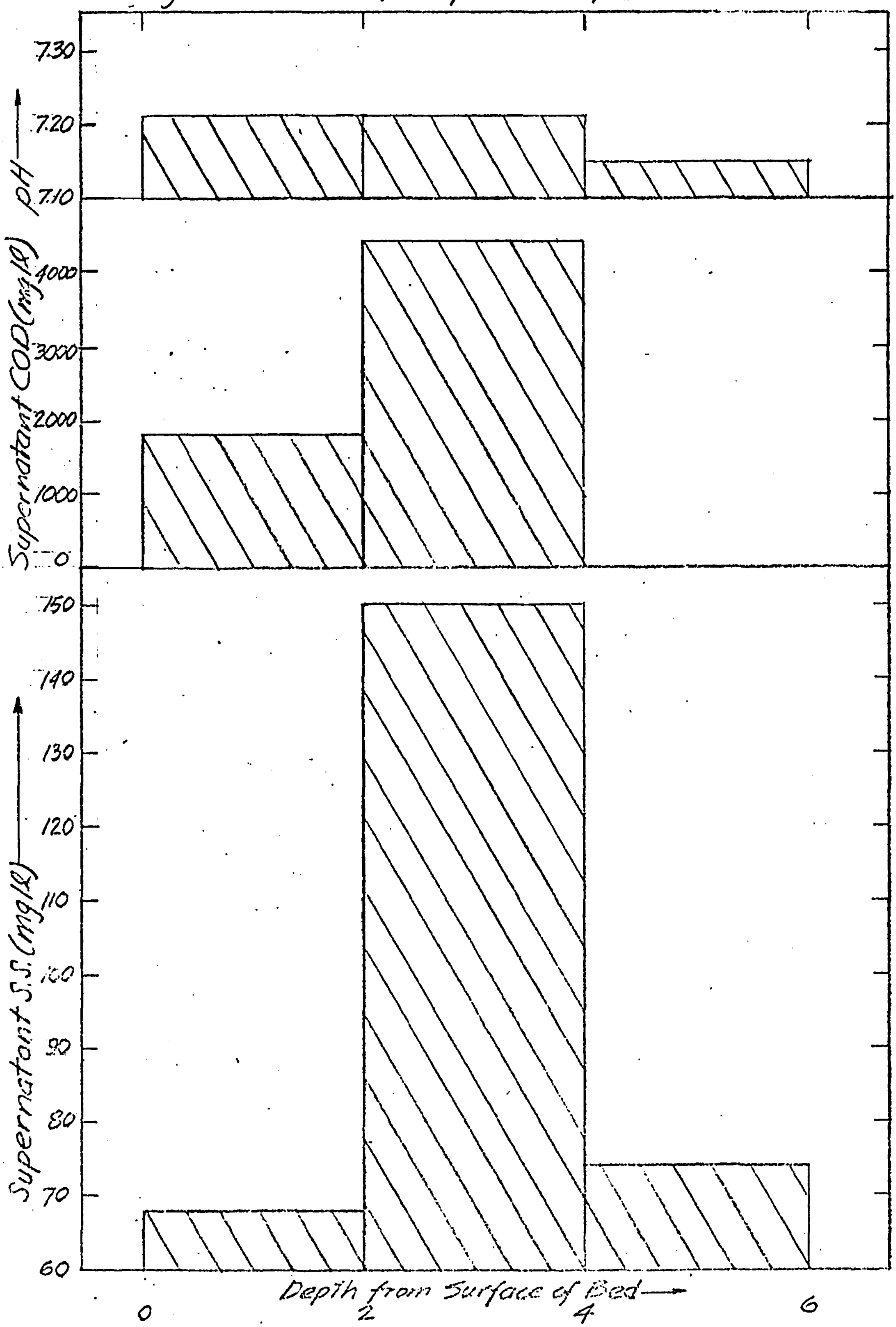


Figure 60G Core Analyses Sample D2

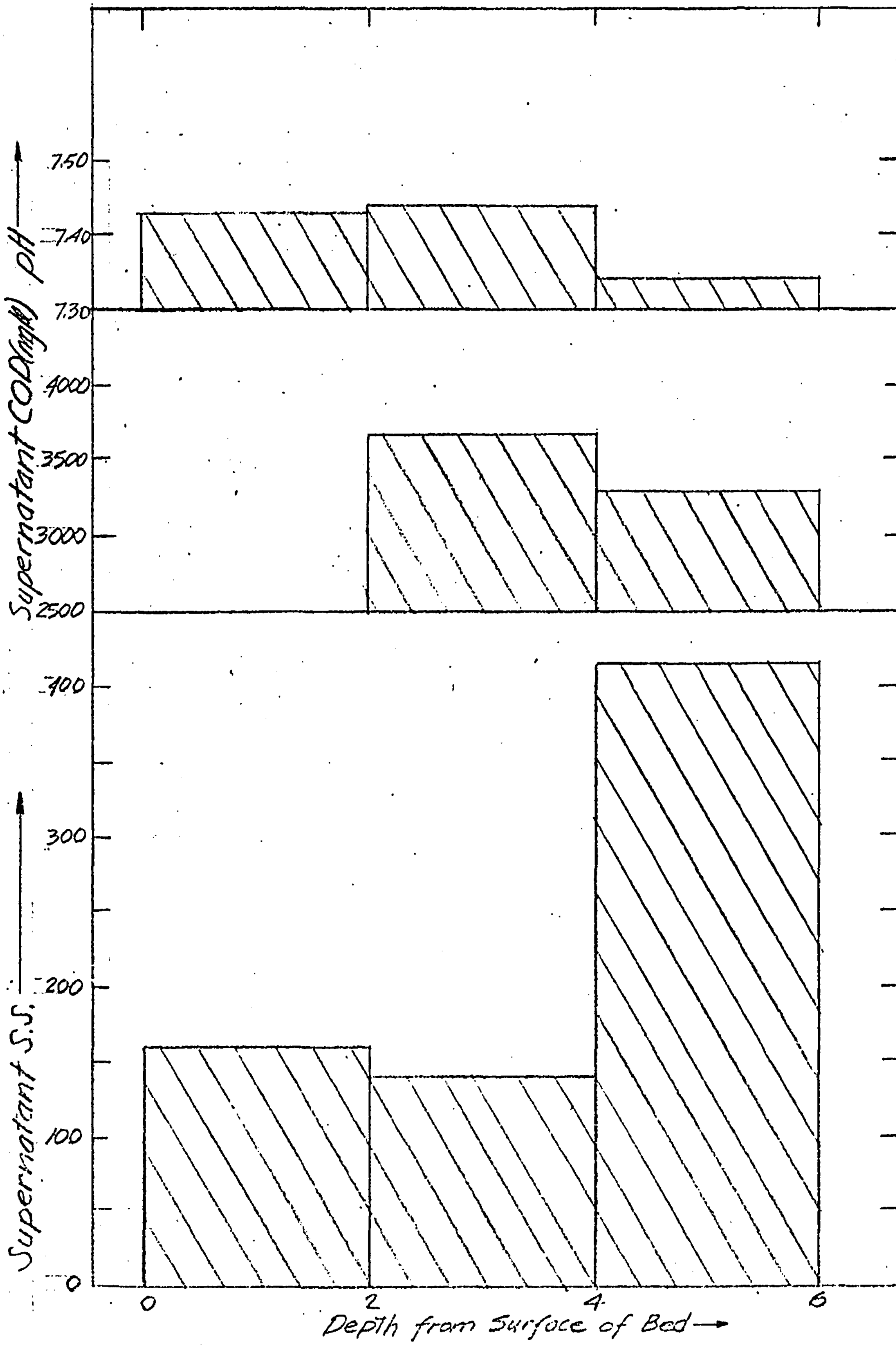


Figure No 60H Core Analyses Sample E1

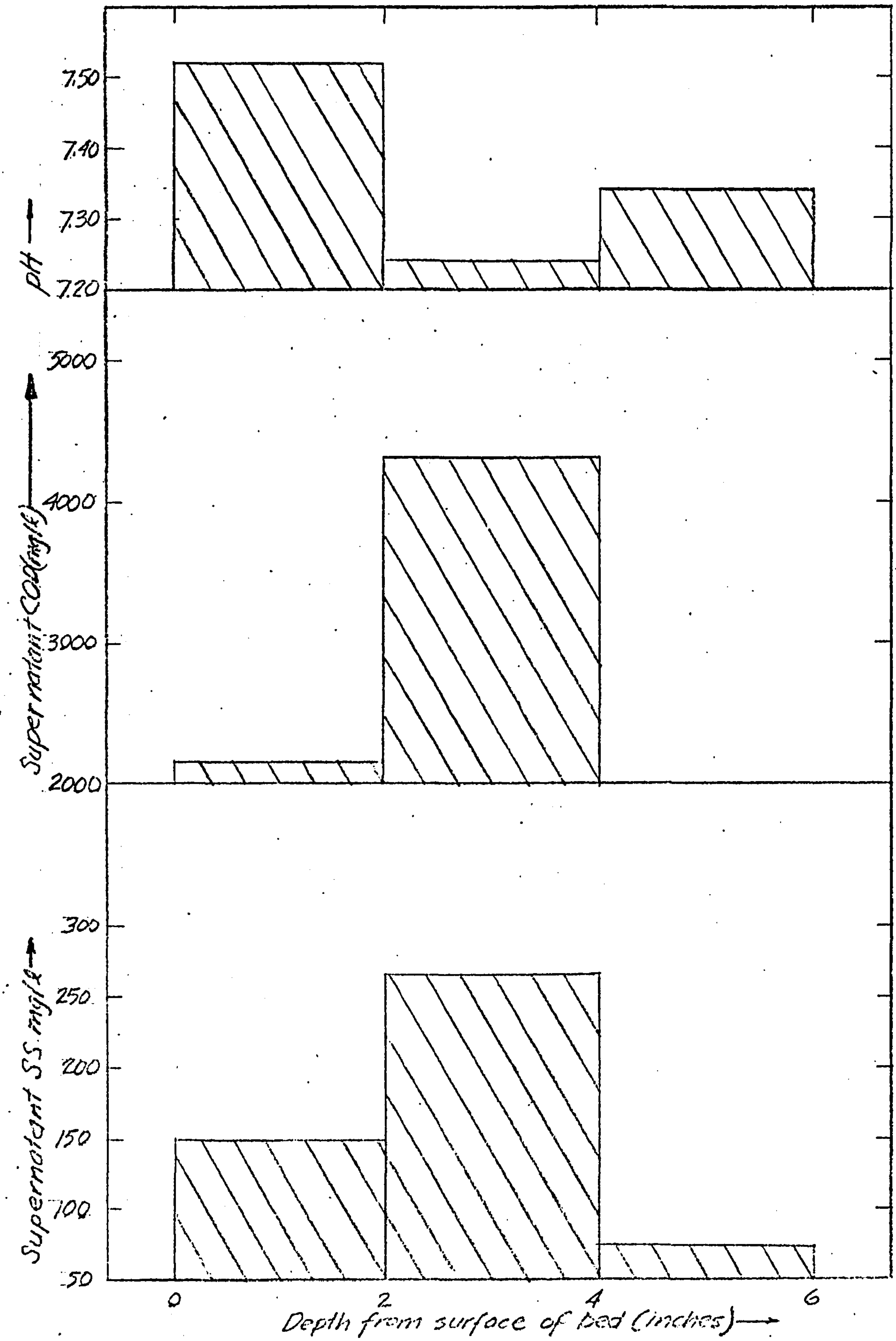


Figure No.60J Core Analyses—Sample E2

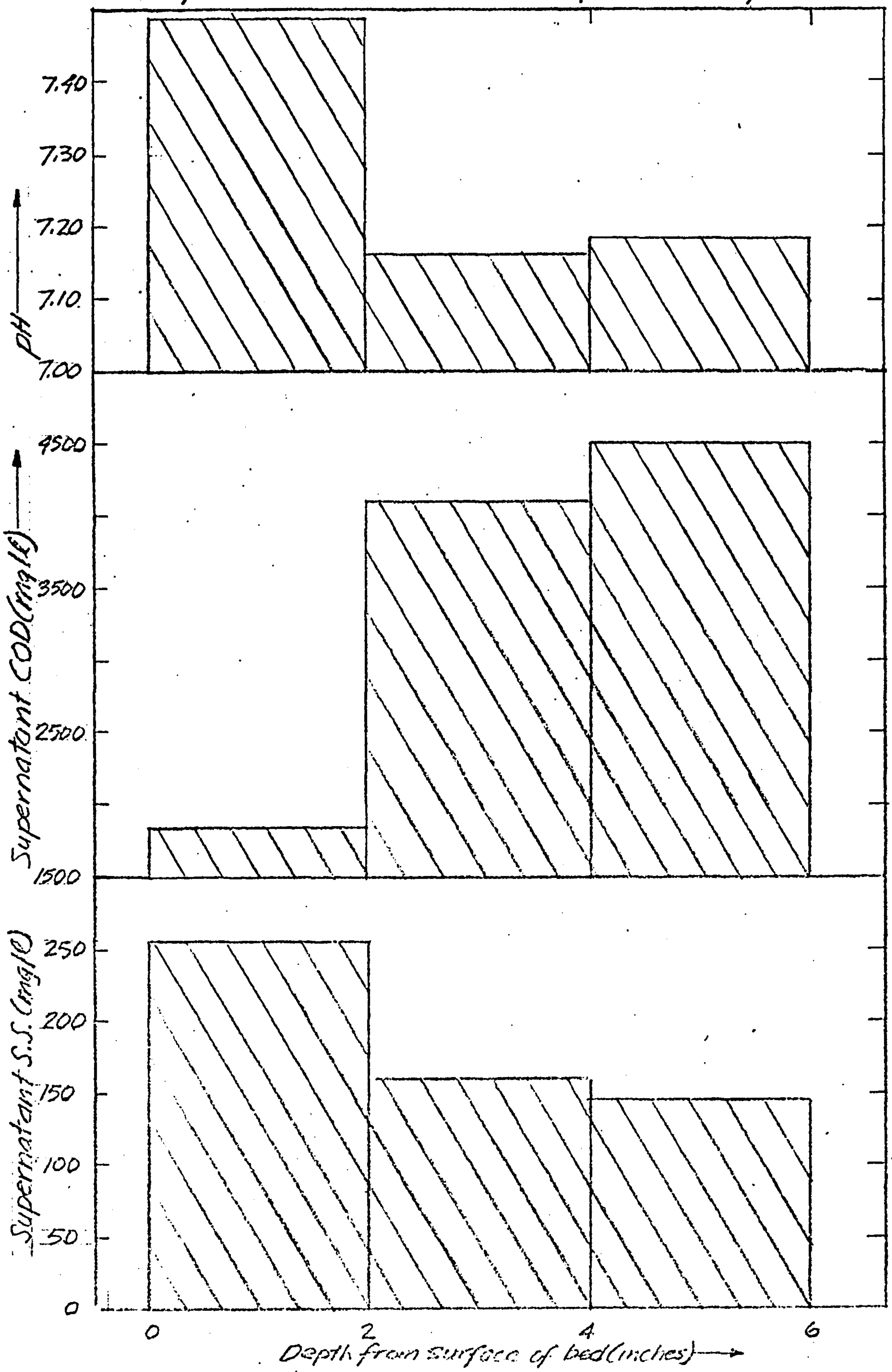


Figure No. 60K Core Analyses Sample E3

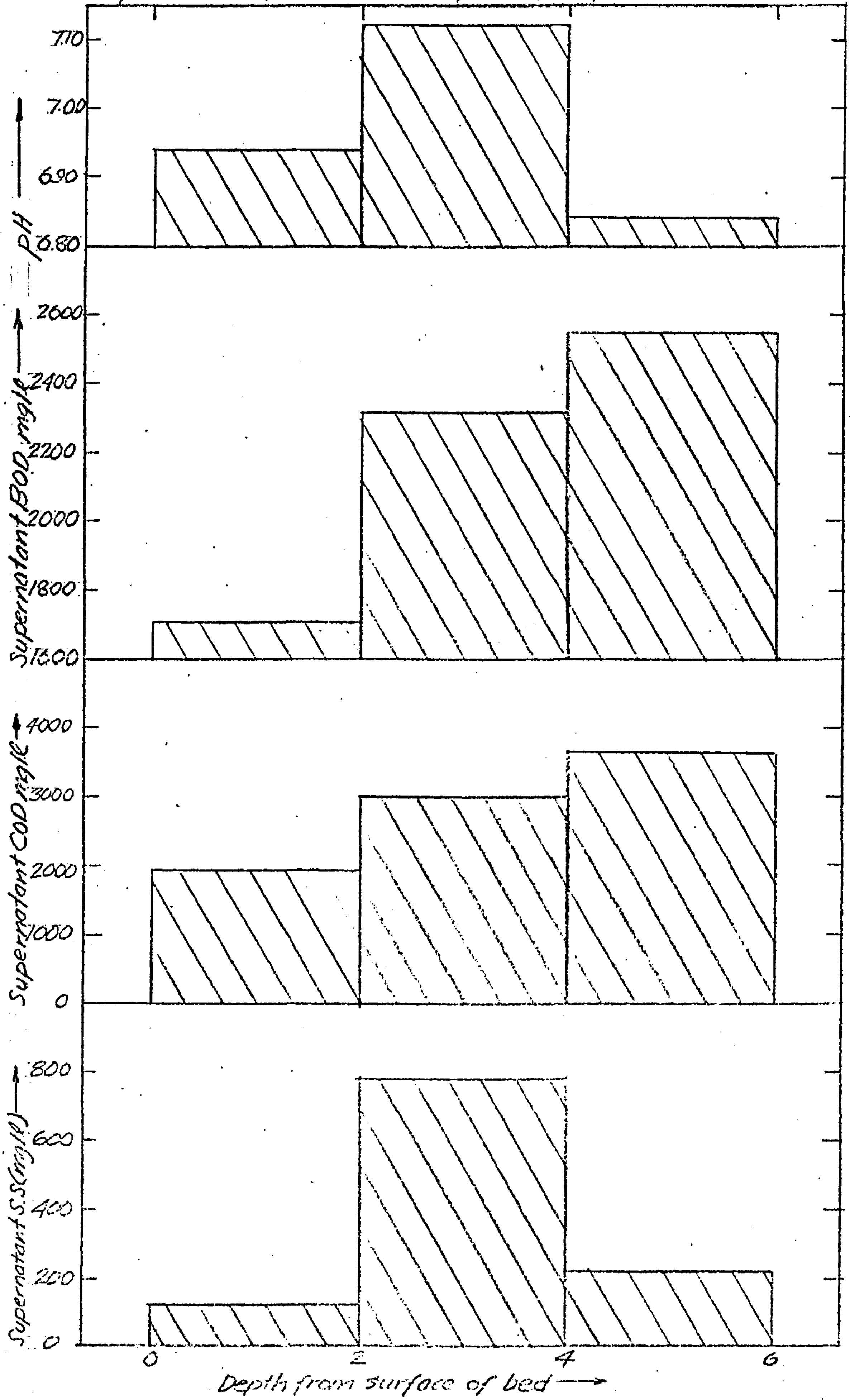


Figure No 60L- Core Analyses - Sample F

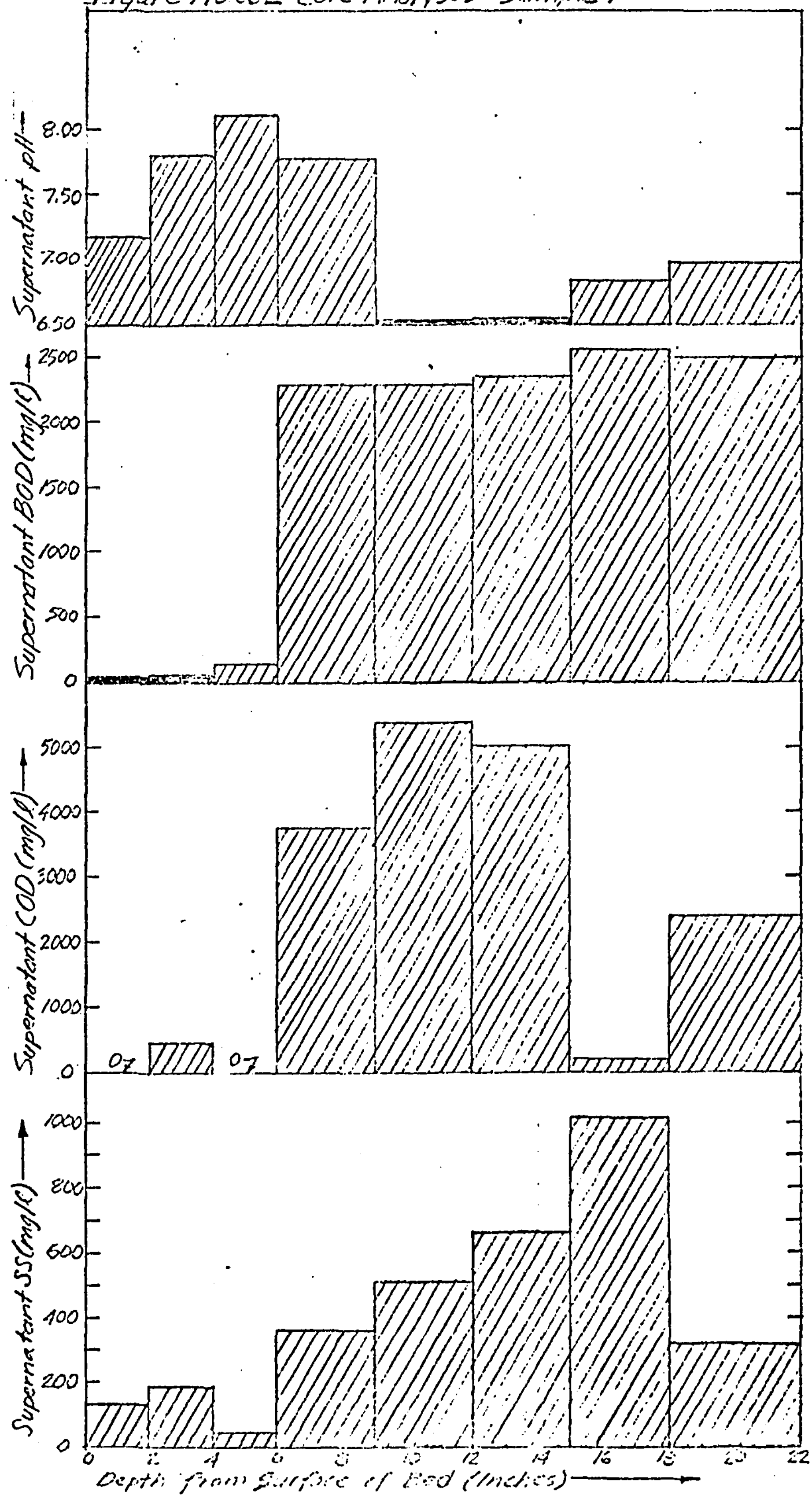


Figure No. 60M Core Analyses Sample H1

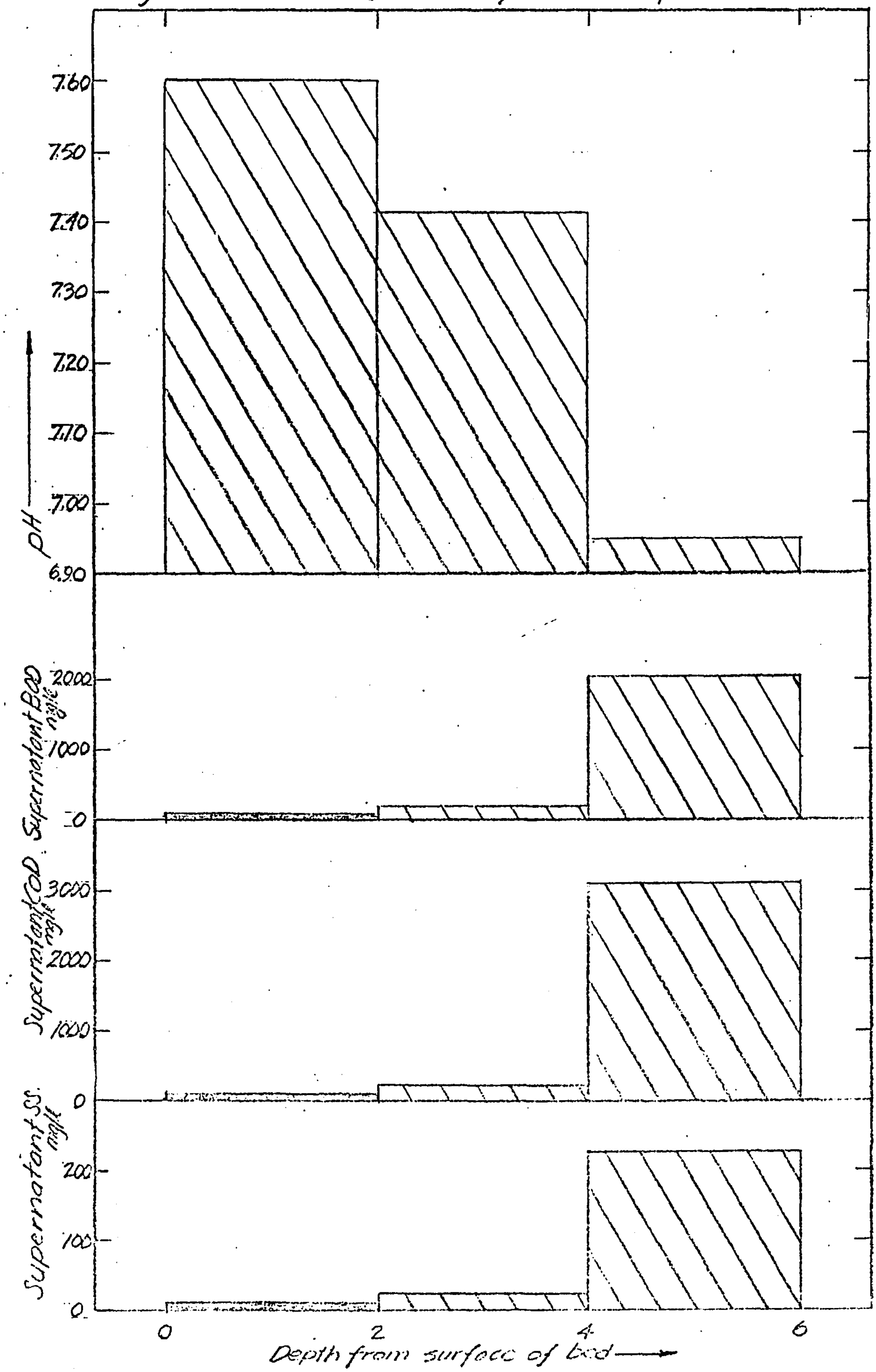


Figure No.60N Core Analyses-Sample J

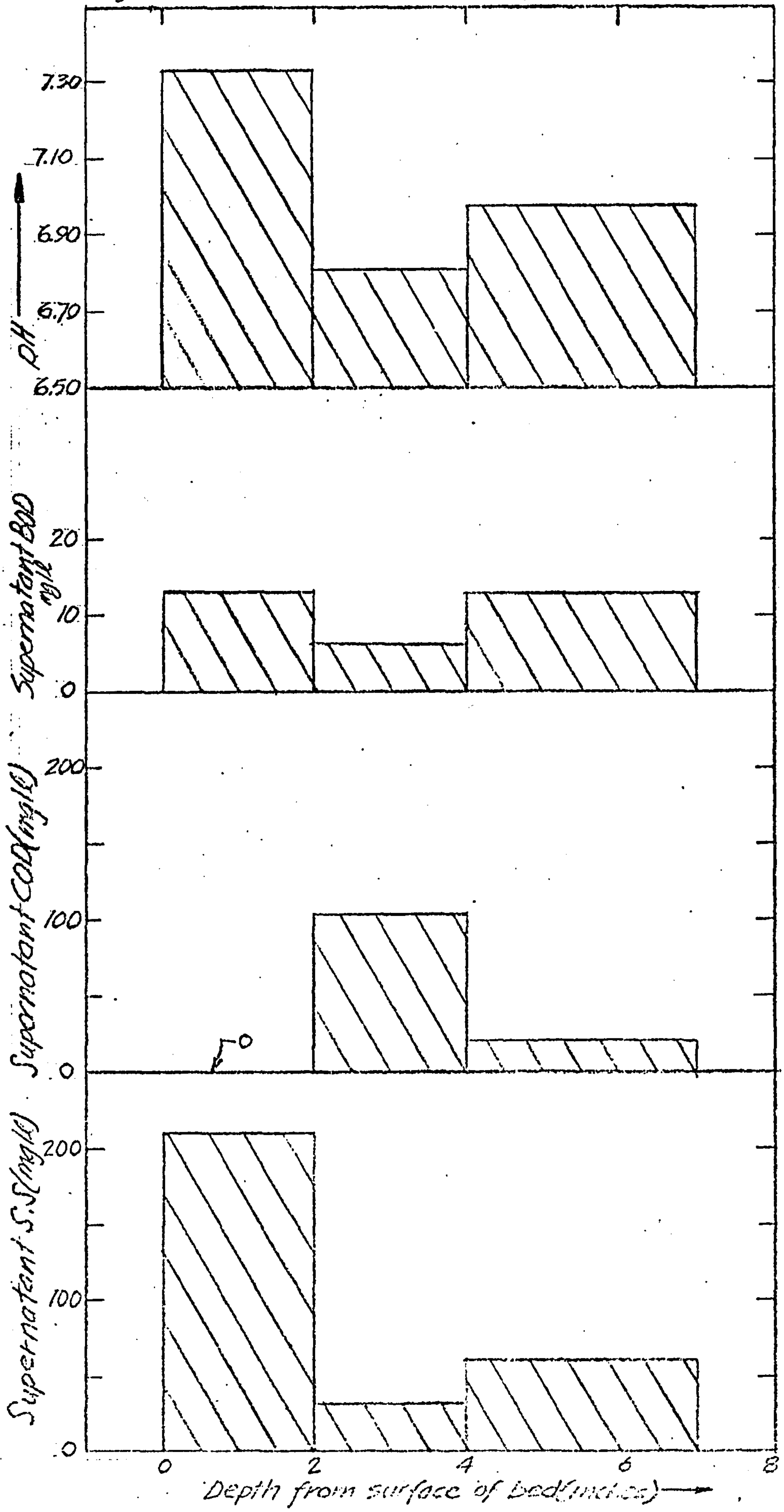


Figure No. 60P Core Analyses-Samples C,F,J

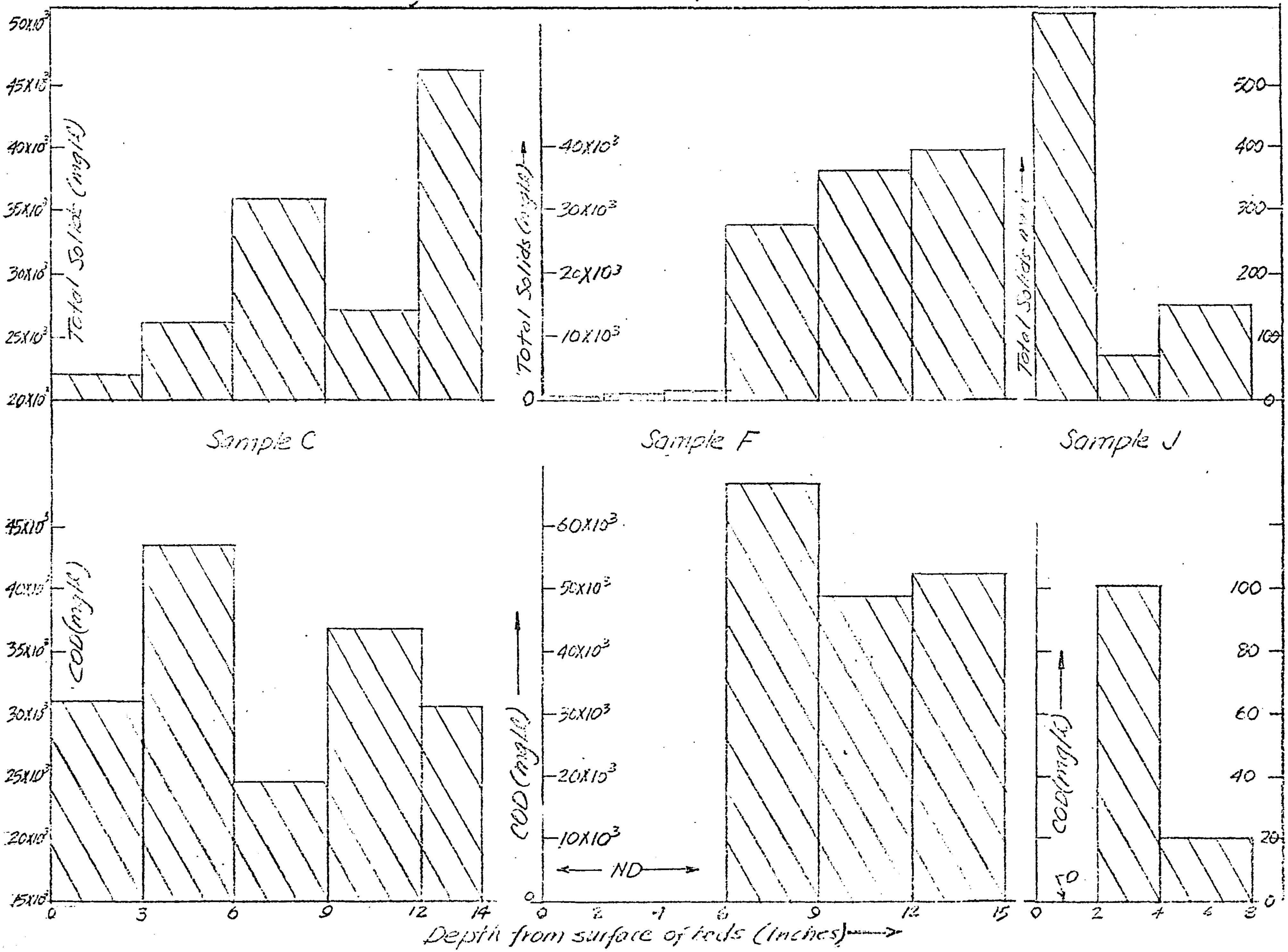


Figure No 60Q Core Analyses-Dewatered Solids

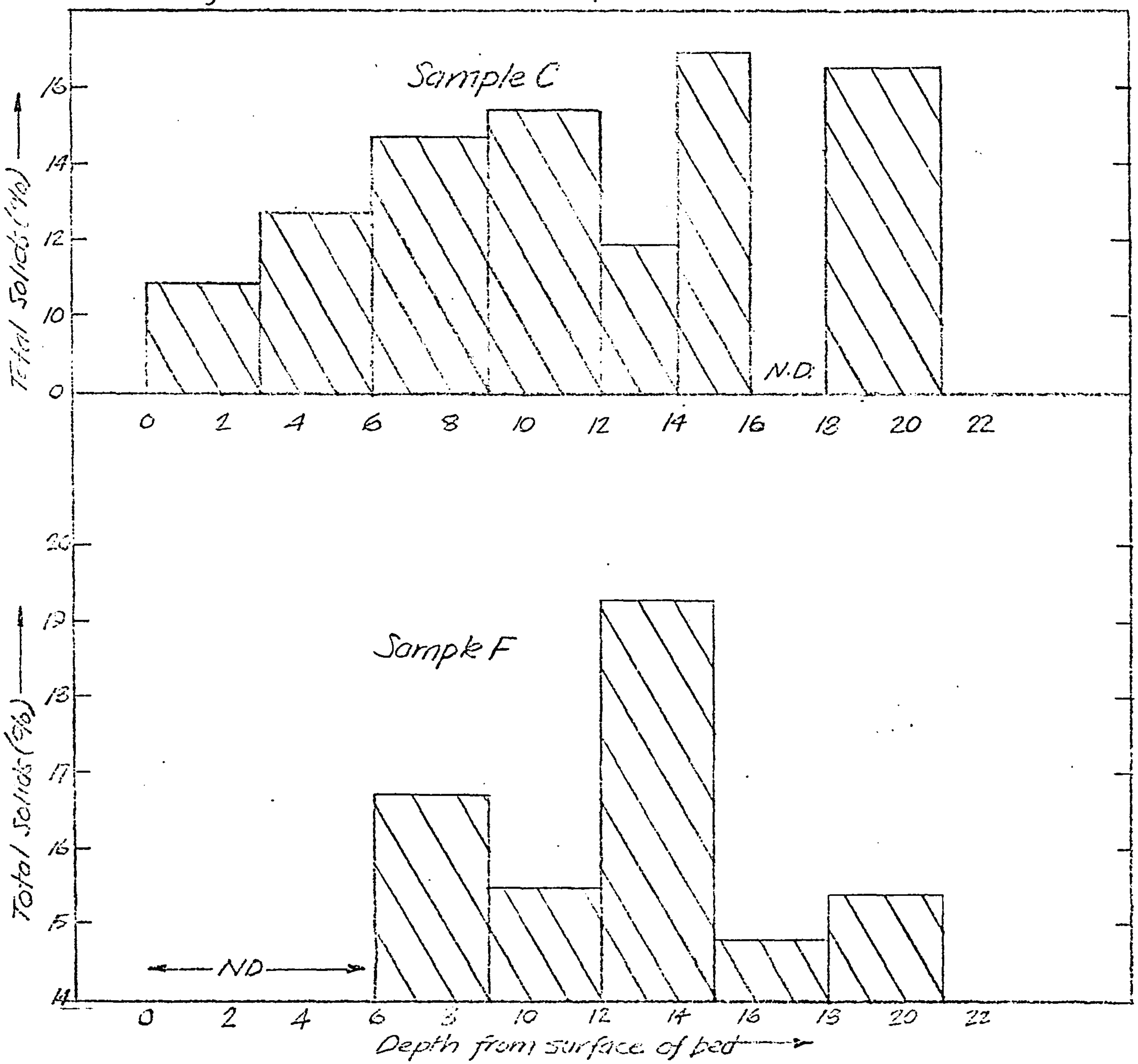


Figure No 63 Drainability of Selected Samples

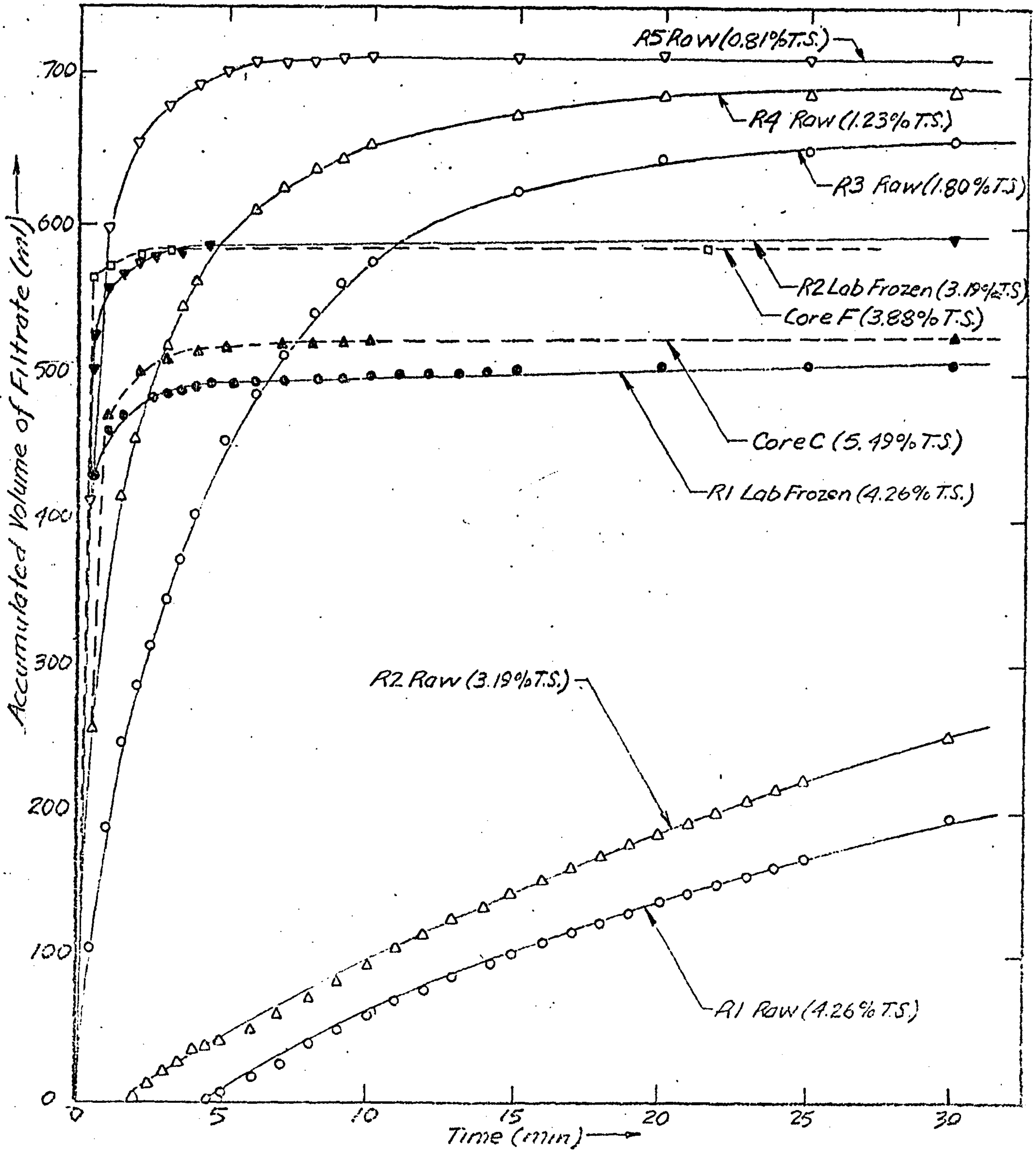


Figure No. 64 Settleable Solids–Raw vs. Frozen

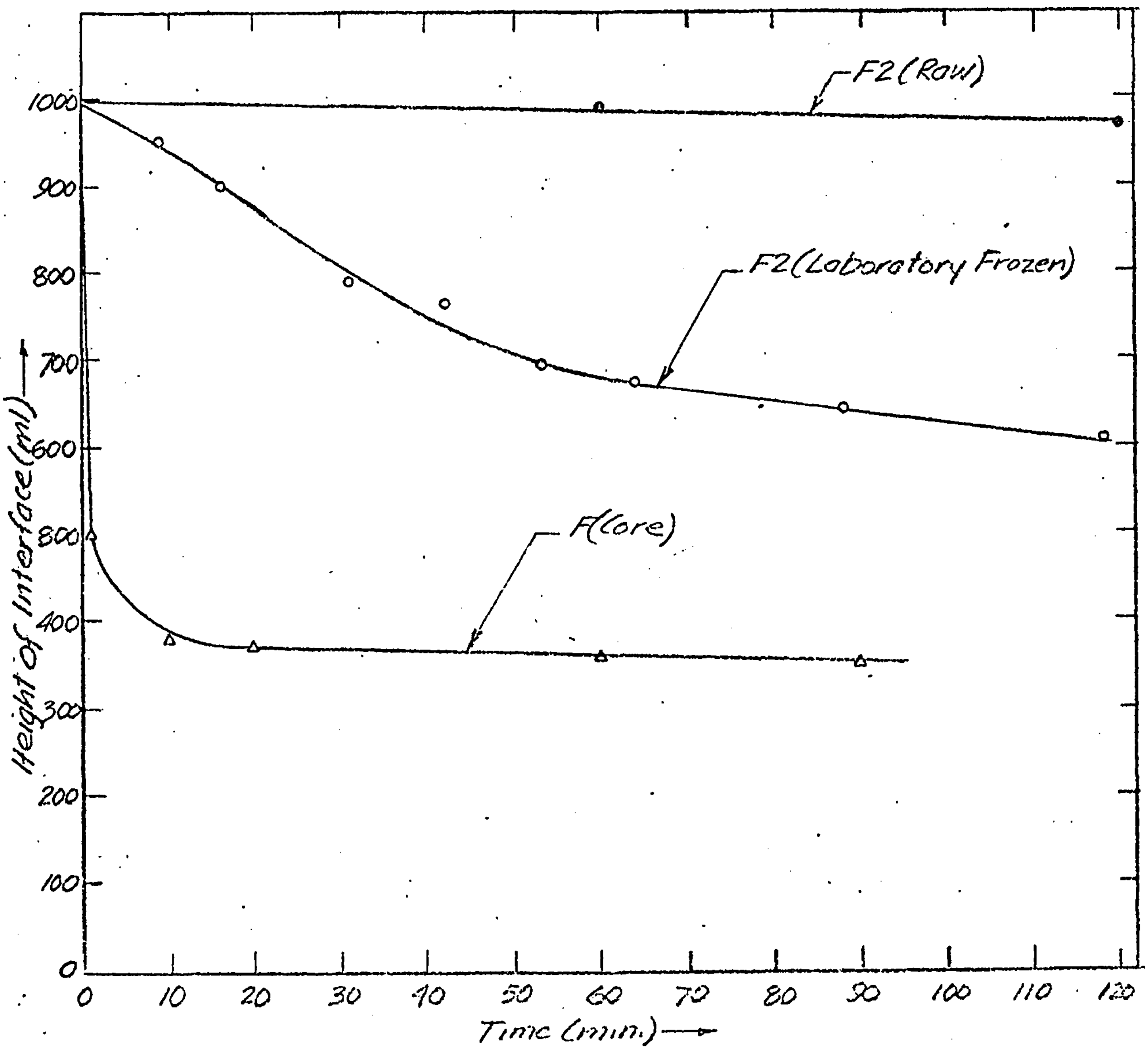


Figure No 65 Settleable Solids - Raw vs Frozen

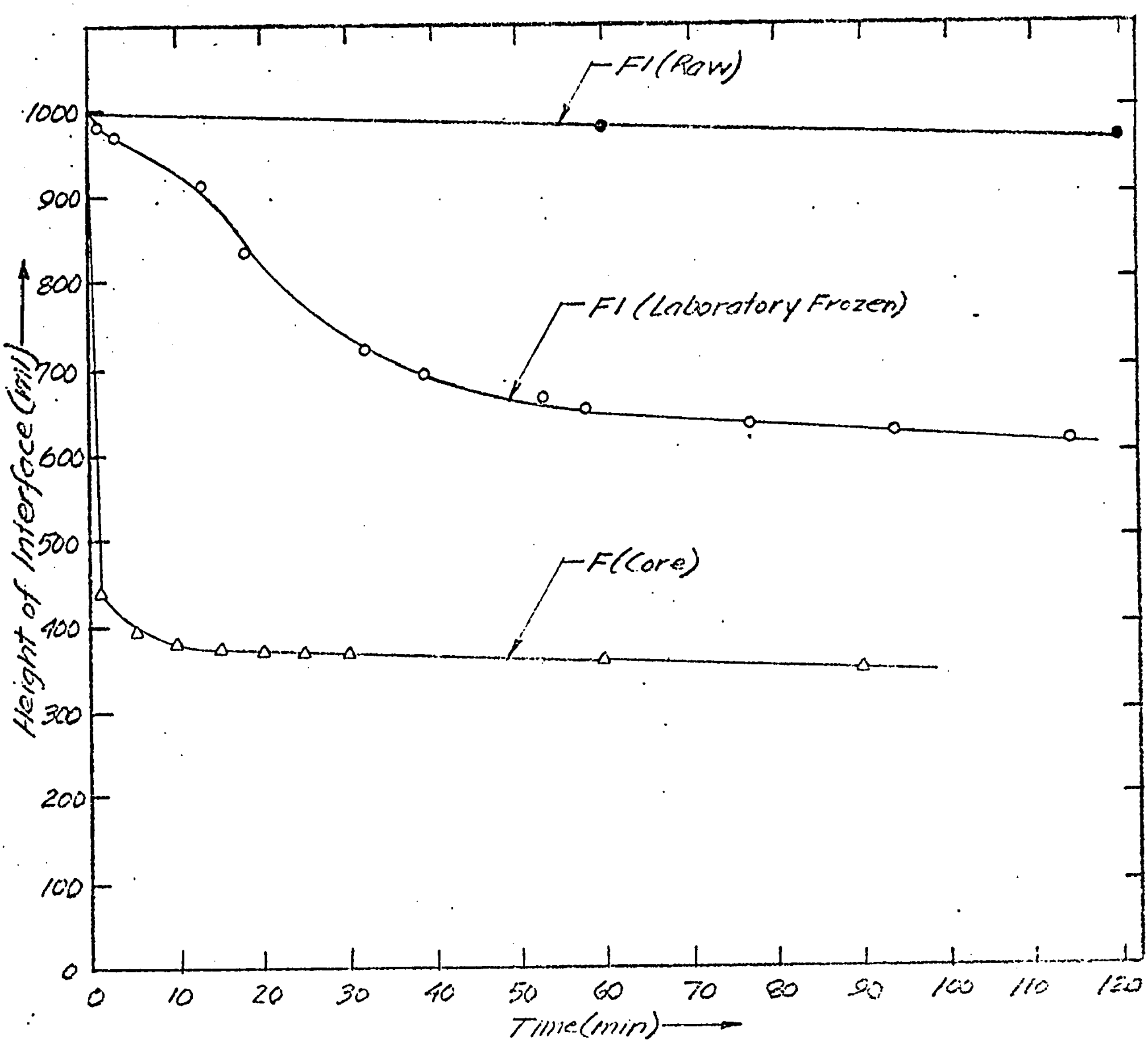


Figure No 66 Settleable Solids - D2 - Raw vs Laboratory Freeze

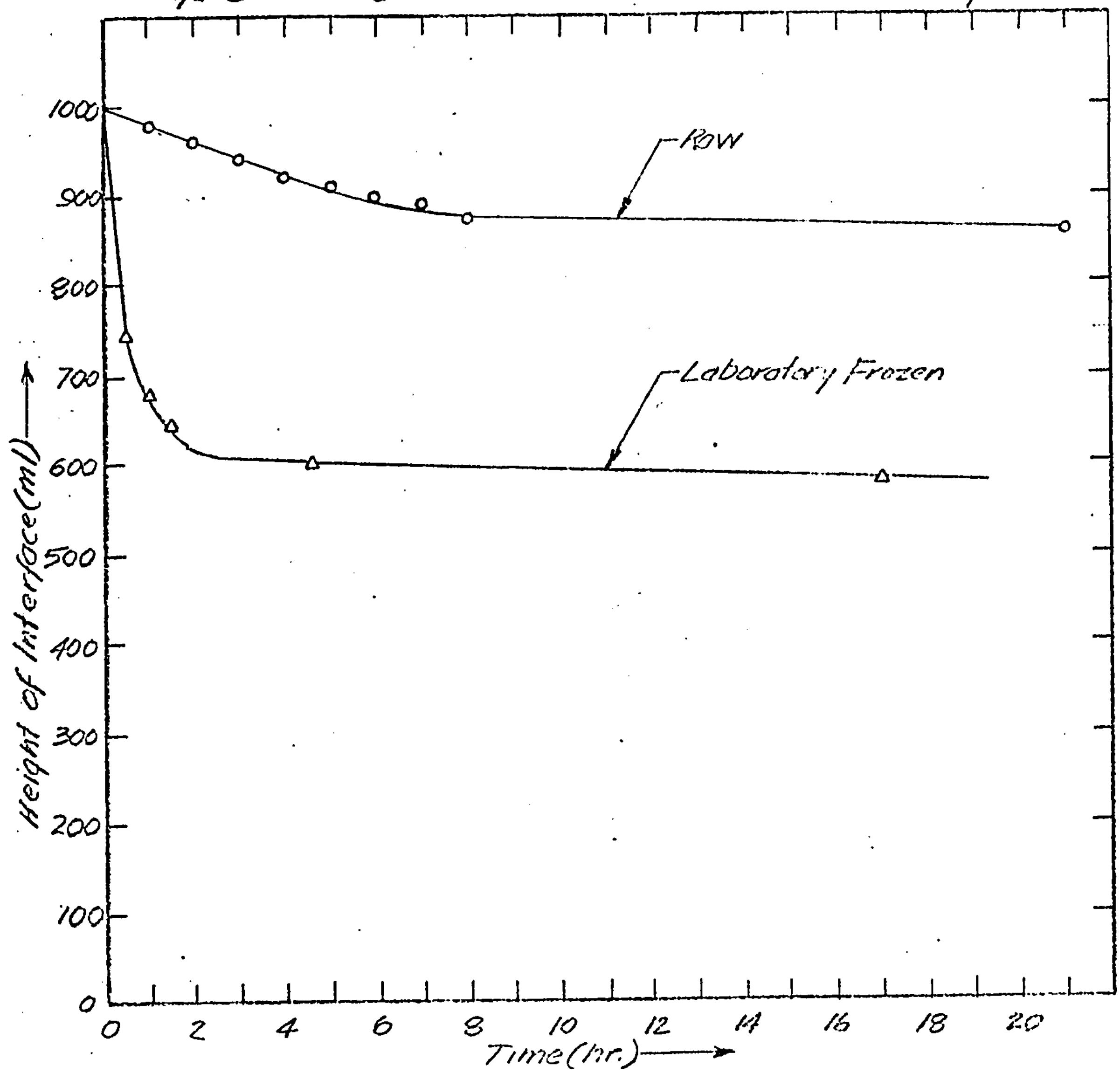


Figure No. 67 Settleable Solids of Lab-Frozen Sludge - 20mg/l Alum vs No Alum

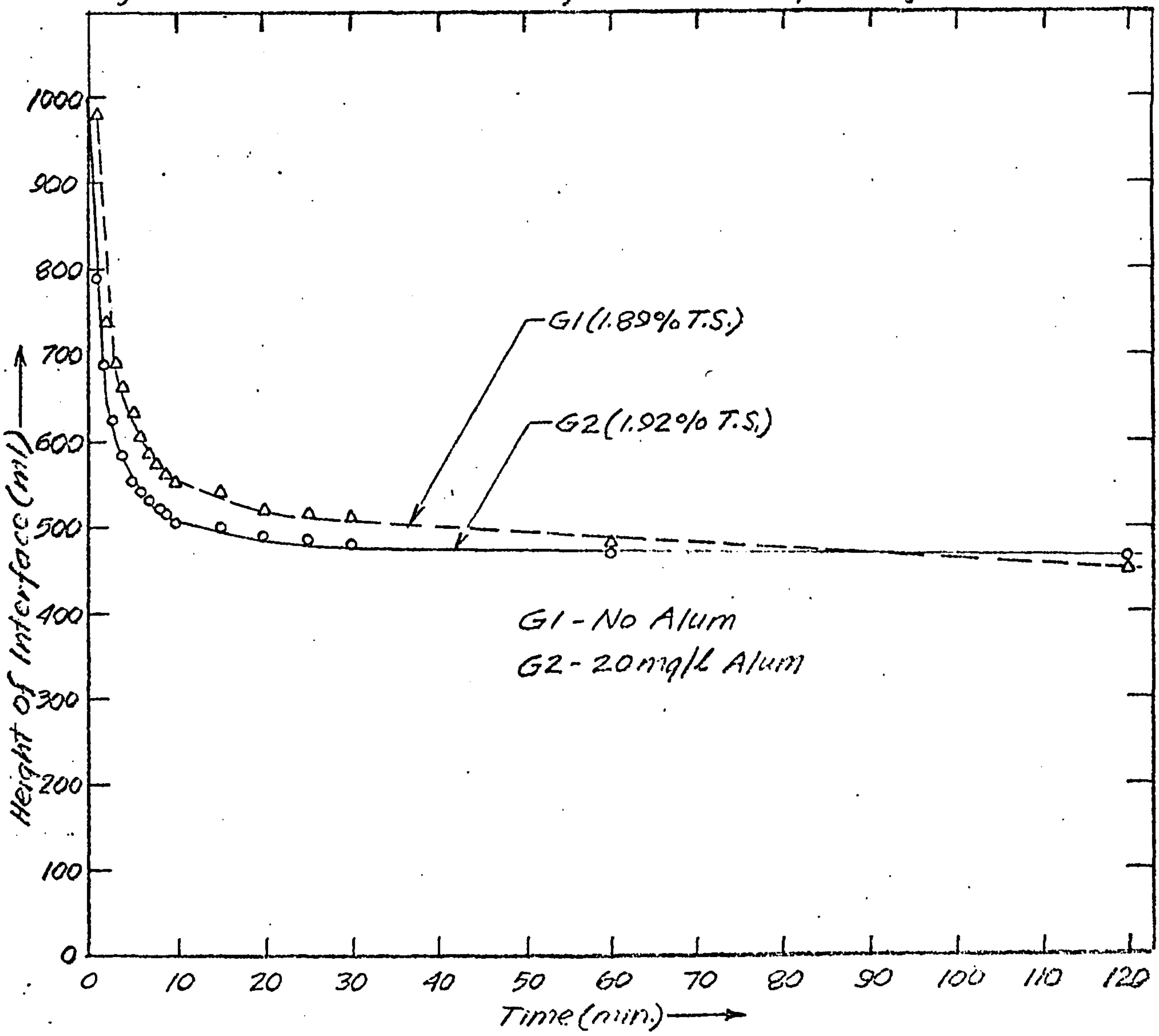


Figure No. 68 Settleable Solids - Raw vs Laboratory Freeze

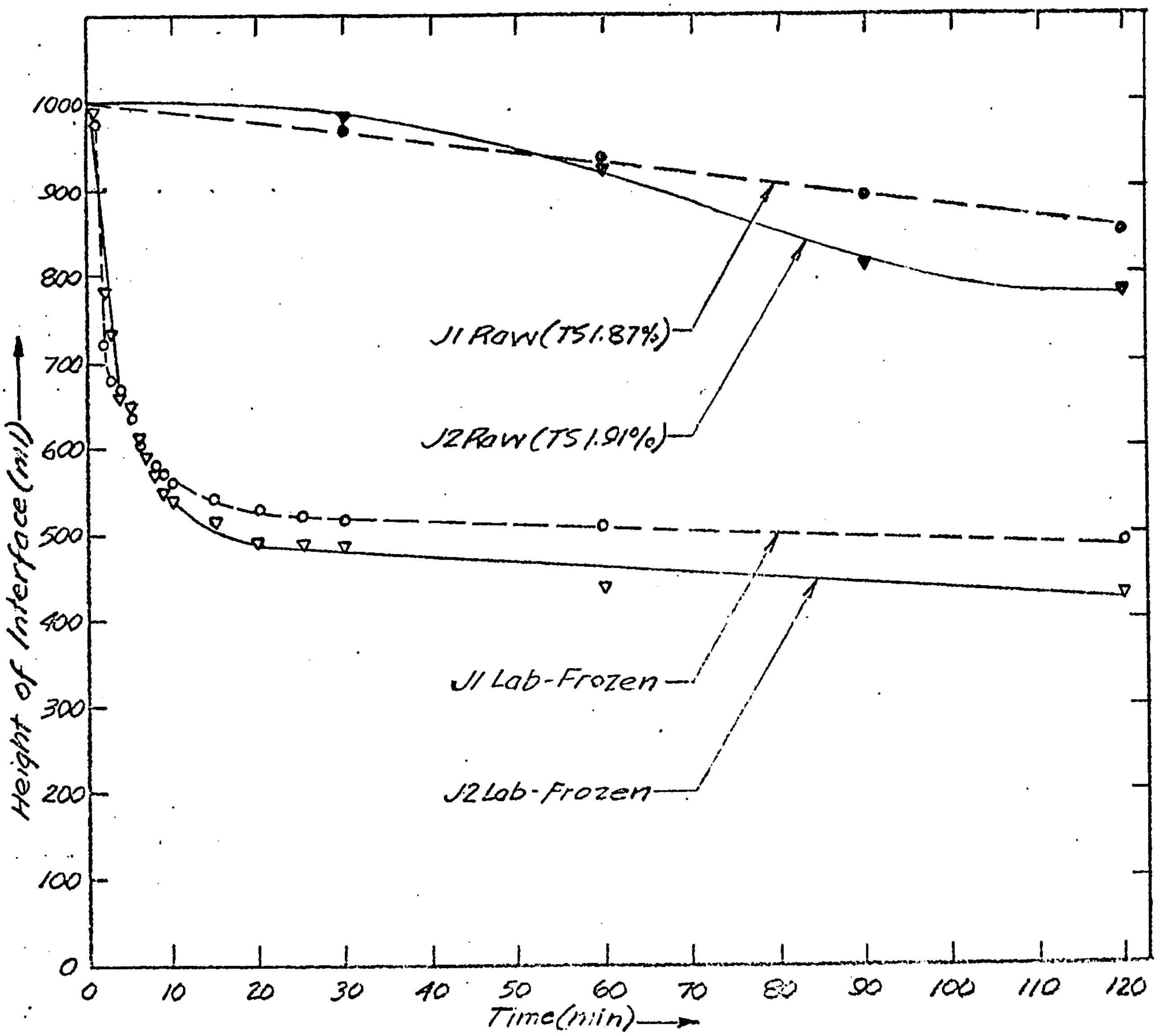


Figure No. 69 Settleable Solids - Raw vs. Lab Freeze with 20 mg/l Alum

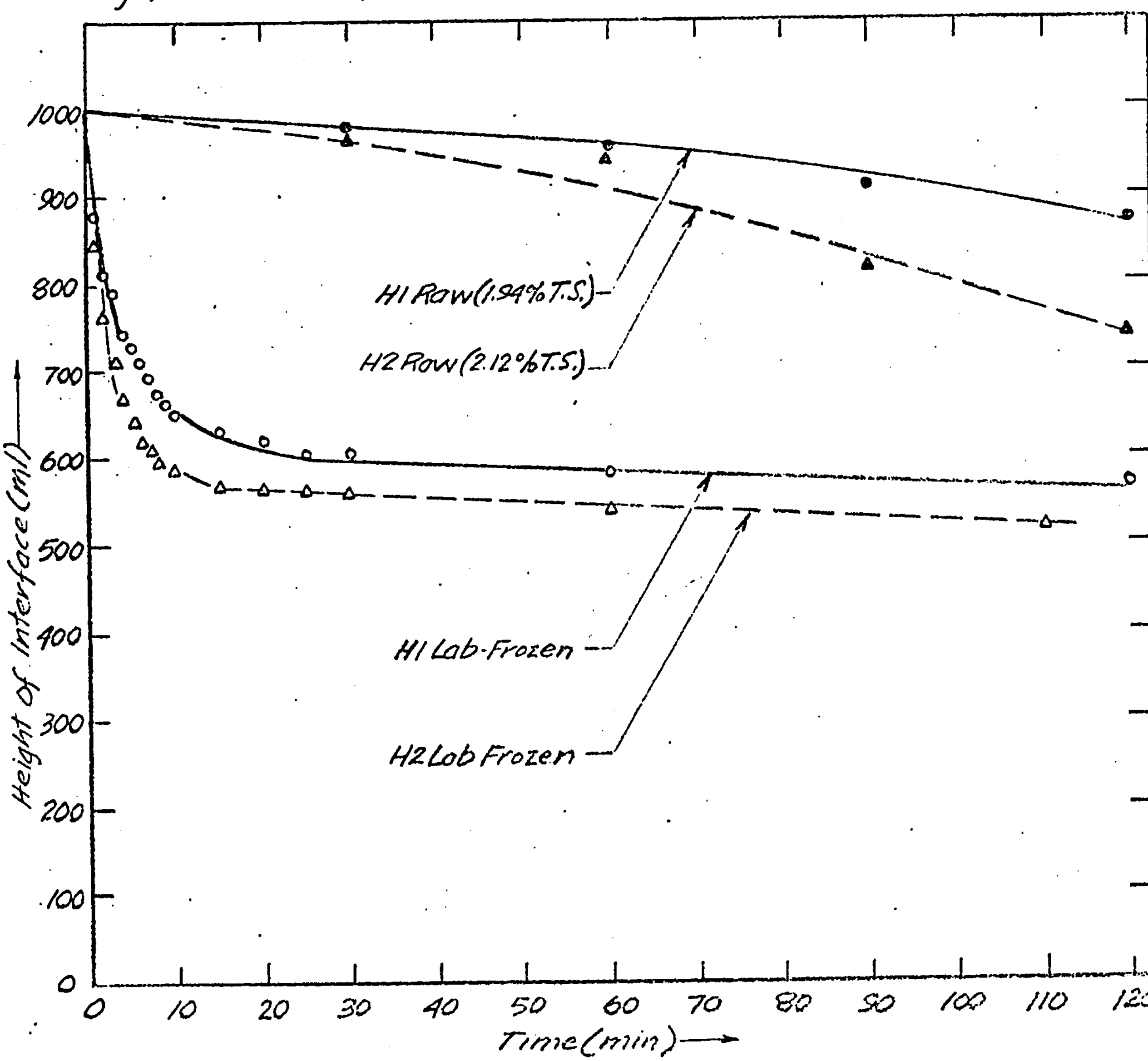
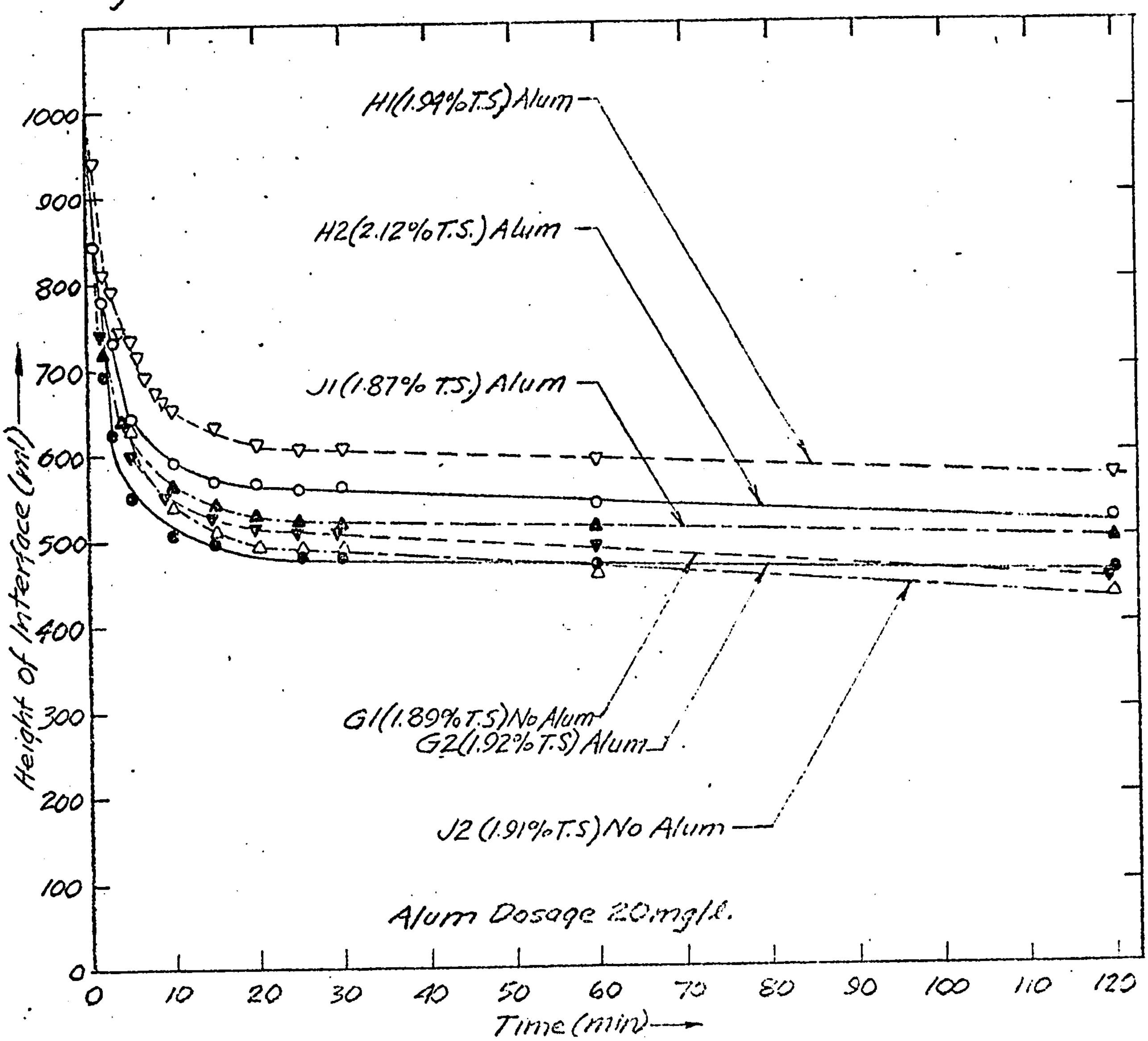


Figure No. 70 Settleable Solids Lab Frozen Sludge - 20 mg/l Alum vs No Alum



III FIELD THAW DATA

FIELD THAW DATA - 1

DATE April 15, 1971 TIME: 3:00 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	9-5/16	1/16	None	Black, felt-like damp surface. Likely insulating effect.
B	6-7/8	1/16	None	Black, felt-like damp surface. Likely insulating effect.
C	21-13/16	None	None	No evidence of thaw. Dry and solid.
D	6-7/16	None	None	Slight thaw at periphery and center.
E	7-9/16	None	None	Slight thaw at periphery and center.
F	22-13/16	None	None	Very little thaw.
G	7-5/8	No sludge at surface	1/2	White surface. Very clear ice.
H	6	No sludge at surface	1	White surface. Ice looks rotten but is solid. Very clear ice.
J	18-3/4	No sludge at surface	1	Some water on surface.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. Beds A, C, F had considerable heaving during freeze.
2. G, H and J showed loss in depth over a period of time; losses in depth shown hereinafter refer to losses between measurements. These beds receive more direct sunlight than the others.
3. No flow as yet from perforated pipes, very little sampleable liquid in beds.
4. Thaw is indicated by progressive blackening from a grey color, except in G, H, J where the surface ice is very clear.
5. No odor in vicinity of beds.

FIELD THAW DATA - 2

DATE April 16, 1971 TIME: 3:50 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH**	REMARKS
A	9-3/16	1/16	1/8	Progressive blackening of surface. Surface damp, Black felty cover.
B	6-5/8	1/16	1/4	Progressive blackening of surface. Surface damp, Black felty cover.
C	21-11/16	None	1/8	Damp surface.
D	6-5/16	None	1/8	Progressive blackening of surface. Surface damp.
E	7-9/16	None	None	Progressive blackening of surface. Surface damp.
F	22-11/16	None	1/8	20% of surface is wet, max. depth of water 1/8".
G	7-3/8	No sludge at surface	1/4	30% wet surface. White ice. Ice starting to shrink from walls.
H	5-7/8	No sludge at surface	1/8	80% of surface is wet, max. depth 1/4". Melt water froze last night-crystals. Water very clear.
J	18-1/2	No sludge at surface	1/4	20% of surface is wet, max. depth of water 1/8".

*These depths are averaged over the area of the bed.
**Since most recent measurements.
Depths are all shown in inches

GENERAL REMARKS:
1. Surface thawing advances from bed walls inward and from thermocouple pole at center outward.
2. No appreciable odor on the site.
3. It appears that as soon as the ice thaws, the melt water is quickly evaporated.

FIELD THAW DATA - 3

DATE April 17, 1971 TIME: 1:15 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	9-3/16	1/8	None	Dry, black mold 1/8" thick. Good insulator. No wall shrinkage.
B	6-5/8	1/8	None	Dry, black mold 1/8" thick. No wall shrinkage.
C	21-5/8	None	1/16	5% of surface wet, film only. Some wall shrinkage.
D	6-5/16	None	None	Thawing from walls inward 4-6" black area on periphery 1 sq. ft. at center, rest is grey.
E	7-7/16	None	1/8	Similar to D. Black area damp. Grey area solid ice.
F	22-11/16	None	None	White ice at surface. 20% of surface is wet-only a film.
G	6-5/8	As before	5/8	10% of surface is wet. White ice on top, thawing at walls.
H	5-3/4	As before	1/8	80% wet, clear water.
J	18-1/4	As before	1/4	40% surface wet, some wall thaw.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odor on the site.
2. No sampleable liquid except on G, H, J.
3. Ice very solid under mold on A and B.

FIELD THAW DATA - 4

DATE April 18, 1971 TIME: 12:30 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	9-1/16	1/8	1/8	Mold growing on surface - good insulator.
B	6-1/2	1/8	1/8	Mold growing on surface.
C	21-3/8	None	1/4	Getting blacker at surface.
D	6-1/4	None	1/16	Surface is now 65% black. Surface is damp.
E	7-7/16	None	None	Surface getting blacker, damp.
F	22-5/8	None	1/16	5% of surface wet-only a film, solid white ice at surface.
G	6-3/8	As before	1/4	Surface water only a film, 5% damp. Shrinkage from all walls.
H	5-3/8	As before	3/8	Thin ice on top of melt water. Froze last night. Water 1/2" deep under ice.
J	17-7/8	As before	3/8	10% of surface wet, 1/4" deep. Some shrinkage of ice from walls.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. G, H, J get more direct sunlight than others.
   D, E get no direct sunlight.
2. No site odor.

FIELD THAW DATA - 5

DATE April 19, 1971 TIME: 4:35 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	8-13/16	-	1/4	Solid ice under 3/8" mold. Mold regrew where removed. Some thaw at periphery.
B	6-1/4	-	1/4	Solid ice under 3/8" mold. Some thaw at periphery.
C	21-1/4	-	1/8	Some damp spots, not much change.
D	6-3/16	-	1/16	70% black ice, no mold. Damp.
E	7-3/8	-	1/16	80% black ice, no mold. Damp.
F	22-1/2	-	1/8	Dry, clear ice at surface.
G	6-1/4	-	1/8	Fairly dry. Less than 5% of surface is damp.
H	5-1/4	-	1/8	Most advanced thawing of all. Considerable shrinkage from wall.
J	17-7/8	-	None	A film of moisture.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odor on site.
2. Gravel pad very wet from surface snowmelt at site, footings on C, F, J starting to fail as gravel approaches quicking condition.
3. Sludge solids in H appear to be quite separate from the clear ice at the surface. The solids appear to be a distinct entity and not included physically in the clear ice.

FIELD THAW DATA - 6

DATE April 20, 1971 TIME: 4:00 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	8-5/8	-	3/16	Solid ice under 1/4" mold. Wet and dark grey under mold. Starting to shrink from walls.
B	6-3/16	-	1/16	Solid damp ice under 1/4" mold. Slight wall shrinkage. A few damp spots on mold.
C	21-1/4	-	None	Not much change. A few damp spots.
D	6-1/8	-	1/16	80% black, damp ice. Some wall shrinkage.
E	7-5/16	-	1/16	Much the same as D.
F	22-1/2	-	None	Still a large solid block of ice. 5% of surface has a water film. White ice at surface.
G	6-1/8	-	1/8	Ice is shrinking from the walls. Ice clarity to at least 2".
H	5-3/16	-	1/16	Similar to G.
J	17-13/16	-	1/16	Excellent ice clarity except where disturbed during core sampling.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. The site is now completely surrounded by local runoff water. The water is not interfering with the beds.
2. No odor on site.
3. Ice melt water either evaporates or finds its way through cracks, wall shrinkage to the underlying sand bed. There is very little moisture on the surface of the beds.
4. Very few visible solids entrained in ice of G, H.
5. Still has been no flow from perforated pipes.
6. Photographs taken this morning.

FIELD THAW DATA - 7

DATE April 21, 1971 TIME: 4:00 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	8-3/8	-	1/4	Mold quickly replaced. Samples taken yesterday. Damp under mold.
B	6-1/8	-	1/16	Thawing at edges.
C	21-1/8	-	1/8	Little change, 5% of surface is damp.
D	5-15/16	-	3/16	Little change, damp surface.
E	7-3/16	-	1/8	Surface getting blacker.
F	22-3/8	-	1/8	Little change.
G	5-7/8	-	1/4	Can see underlying solids at bed periphery - good separation.
H	4-15/16	-	1/4	Almost completely thawed.
J	17-5/8	-	3/16	Ice is shrinking from walls.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. Removed plugs from perforated pipes - still no flow.
2. No odor on site.
3. Considerable runoff encircling site but not interfering with beds.

FIELD THAW DATA - 8

DATE April 22, 1971 TIME: 4:15 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	8-1/8	-	1/4	Not much change.
B	5-15/16	-	3/16	Thawing progressing slowly.
C	21	-	1/8	Not much change.
D	5-15/16	-	None	Surface moist, black. Not much change
E	7-1/16	-	1/8	Surface moist, black.
F	22-3/8	-	None	Not much change.
G	5-5/8	-	1/4	Ice shrinking from wall considerably.
H	4-13/16	-	1/8	Only about 1" of clear ice left above solids.
J	17-3/16	-	3/16	Not much change.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odor on site.

FIELD THAW DATA - 9

DATE April 23, 1971 TIME: 3:30 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	8	-	1/8	Damper in depressions. Mold 1/4" thick.
B	5-15/16	-	None	Same as A.
C	20-7/8	-	1/8	Not much change. 5% of surface is damp.
D	5-3/4	-	3/16	Getting blacker. Damp - no sampleable liquid.
E	6-15/16	-	1/8	Same as D.
F	22-3/16	-	3/16	Very little change. Some liquid in ice depressions-very clear.
G	5-7/16	-	3/16	Little change. Wall shrinkage shows complete separation of solids and clear ice.
H	4-5/8	-	3/16	Ice shrinkage from North and West walls - direct radiation from sun.
J	17	-	3/16	Liquid in low area at North wall, about 1/2" deep.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No site odor.

FIELD THAW DATA - 10

DATE April 24, 1971 TIME: 3:40 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	7-7/8	-	1/8	Not much change.
B	5-5/8	-	5/16	Mold 1/4" thick, dry sludge is wet underneath but still solid, black.
C	20-1/2	-	3/8	Not much change.
D	5-7/16	-	5/16	Black, surface damp. Ice still solid. No sampleable liquid.
E	6-11/16	-	1/4	Same as D but less ice shrinkage from walls.
F	21-15/16	-	1/4	Not much change. No sampleable liquid.
G	4-15/16	1/8	1/2	Looks like about 1/2" clear ice above solids, except 15% exposed where thaw is more advanced.
H	4-1/8	1/4	1/2	Exposed sludge about 25% of surface. Thickest ice in S.E. corner - 1". Sludge has musty odor.
J	16-5/8	-	3/8	Not much change. Liquid between frozen mass and walls.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No site odors.
2. Considerable local runoff from snowmelt but beds are not yet affected.
3. No evidence of liquid drainage through perforated pipe.
4. No water in G or H. Reported thawed sludge depth refers only to areas of the boxes where advanced thawing has taken place due to direct sun radiation.
5. First day of sampling sludge solids.
6. Good drying wind blowing.

FIELD THAW DATA - 11

DATE April 25, 1971 TIME: 4:00 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	7-13/16	-	1/16	Not much change.
B	5-3/16	-	3/16	Not much change.
C	20-1/8	-	3/8	Damp in spots. No sampleable liquid.
D	5-3/16	1/8	1/4	Black wet layer at surface. No released liquid. Starting to thaw from top.
E	6-3/8	1/8	5/16	Same as D. Black ice under melted layer.
F	21-7/16	-	1/2	Not much change.
G	4-5/8	1/4	5/16	Solid ice under melted layer. 25% exposed sludge- NW corner. Musty odor in bed.
H	3-15/16	3/8	3/16	40% exposed sludge - NW corner. Clear ice distinct separation from solids. Solid ice below melted layer.
J	16-5/16	-	5/16	Slight odor in bed. Ice very clear at surface.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odor on site, local snow runoff conditions stable.
2. A, B, D, E have considerable solids at the surface of the beds. It appears that these sludge runs experienced very little settling before freezing and very little solids rejection during freezing.
3. No odor on site.

FIELD THAW DATA - 12

DATE April 26, 1971 TIME: 5:30 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	7-5/16	-	1/2	Little change.
B	5-3/16	-	None	Little change. Mold has stabilized at 1/4-1/2" depth.
C	19-7/8	-	1/4	Little change.
D	5	1/8	3/16	Melted sludge is wet but no sampleable liquid.
E	6-1/4	1/8	1/8	Same as D. Solid black ice below thawed layer.
F	21-7/16	-	None	No change.
G	4-1/4	3/16	3/8	50% exposed sludge - NW corner. Clear ice in SE corner. No sampleable liquid.
H	3-13/16	5/16	1/8	60% exposed sludge. Solid ice below thawed layer. Ice is dry.
J	16	-	5/16	Little change. Clear ice where undisturbed. Very little water-film in less than 5% of area.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odor on site, a good dry wind is blowing.
2. Local snow runoff encroaching within site but still not influencing beds.
3. Note daylight saving time now in effect - lost one hour.
4. Liquid seems to dry as fast as sludge thaws and releases it.

FIELD THAW DATA - 13

DATE April 27, 1971 TIME: 2:00 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	7-5/16	-	0	Dry inside and outside bed. Not much change.
B	5-1/8	-	1/16	Bed dry inside and outside. Not much change.
C	19-7/8	-	0	Mold slightly increasing.
D	5	-	0	Melted sludge layer temporarily frozen.
E	6-1/4	-	0	Same as D.
F	21-1/4	-	3/16	Dry, not much change.
G	4-1/4	-	0	Thawed sludge layer temporarily frozen.
H	3-3/8	-	7/16	60% exposed sludge solids. Thawed sludge layer is temporarily frozen.
J	15-15/16	-	1/16	Dry, not much change.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. Thaw does not appear to be uniform. This is due to:
   - varying thermal characteristics from bed to bed radiation, insulation (natural and syrafoam)
   - varying measurement times; beds could be in different stages of expansion and contraction depending on direction of heat flow.
   - shortcomings of averaging technique.
2. No odor on site.
3. Thawed sludge mat depths haven't changed since yesterday, today they are simply frozen due to cold temperatures last night.
4. Photographs taken this afternoon.
5. No sampleable liquid in any of the beds.

FIELD THAW DATA - 14

DATE April 28, 1971 TIME: 3:30 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	7-1/8	-	3/16	Very dry-not even damp below mold. Ice very solid.
B	4-7/8	-	1/4	Same as A.
C	19-11/16	-	3/16	Dry, not much change. Black ice at surface.
D	4-15/16	1/8	1/16	Dry, thawed sludge layer is very dry, black color.
E	6	1/8	1/4	Same as D.
F	21-3/16	-	1/16	Very dry. Ice is clear but not as clear as J, much clearer than C.
G	4-1/8	3/8	1/8	65% exposed sludge solids. Very dry, except thawed sludge layer.
H	3-1/4	1/2	1/8	65% exposed sludge.
J	15-7/8	-	1/16	Very dry on surface. Some water between frozen sludge mass and walls.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odor on site, cold, snowing.
2. Local snow runoff not yet interfering with beds but starting to undermine foundations of C, F, J.
3. Thawed sludge layers on D, E receiving additional freeze-thaw cycle by nighttime freezing. Dehydrating effect. Thawed sludge layers on G, H now attaining some shear strength and are 'forkable'. Very manageable product.

FIELD THAW DATA - 15

DATE April 29, 1971 TIME: 4:30 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	7-1/8	-	0	Not much change. Dry
B	4-7/8	-	0	Not much change. Dry
C	19-5/8	-	1/16	Not much change. Dry. Surface ice very black.
D	4-15/16	-	0	Homogeneous black surface. Thawed sludge layer temporarily frozen.
E	6	-	0	Same as D.
F	21-3/16	-	0	Dry. Surface ice has very few solids but is opaque.
G	4-1/8	-	0	Dry. Not much advance in thaw.
H	3-1/4	-	0	Dry, Not much change. Musty odor in bed.
J	15-3/4	-	1/8	Surface ice has very few solids-very clear. Dry, not much change

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. Snowmelt runoff water is frozen; generally dry, frozen conditions on site. Very little thaw and appears to be negligible loss due to sublimation.
2. No odor on site.

FIELD THAW DATA - 16

DATE April 30, 1971 TIME: 4:30 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	7-1/8	-	0	Not much change, Dry.
B	4-13/16	-	1/16	Same as A.
C	19-1/2	-	1/8	Same as A.
D	4-15/16	-	0	Not much change, surface very dry.
E	5-15/16	-	1/16	Same as D.
F	21-1/16	-	1/8	Not much change, dry.
G	4	3/8	1/8	Solid ice below thawed layer. Thawed layer quite dry.
H	3-1/4	1/2	0	Same as G.
J	15-3/4	-	0	Not much change. Some liquid between ice structure and box at NW corner.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odor on site.
2. Thawed sludge layer on D, E "forkable".
3. Thawed sludge layer on D, E, G, H is acting as an effective surface insulators, retarding heat transfer.
4. Box J has tilted in a southerly direction due to a foundation failure caused by gravel quicking. This bed will now receive more direct sunlight from south and southwest.

FIELD THAW DATA - 17

DATE May 1, 1971 TIME: 4:00 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	7-1/16	-	1/16	Not much change, mold still 1/2" thick - dry top and bottom.
B	4-3/4	-	1/16	Same as A.
C	19-7/16	-	1/16	Not much change.
D	4-13/16	3/16	1/8	Thawed sludge layer quite dry.
E	5-15/16	3/16	0	Same as D.
F	21-1/16	-	0	Not much change; box is starting to tilt southerly.
G	3-13/16	1/2	3/16	65% exposed sludge solids. Remainder is clear ice above sludge solids.
H	3-1/16	3/4	3/16	70% exposed sludge solids. Solid ice below thawed layer.
J	15-3/8	-	3/8	15% of surface is wet. Water 1" deep in NW corner. Looks like it is thawing mainly from the top downwards.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. The foundation of F failed at 3:45 PM today. F is now tipped at a 25 degree angle to the horizontal and will receive more direct radiant energy from the sun. Perforated pipe is extended into a pool of local snow runoff water but the runoff water is not interfering with the thaw.
2. Musty, earthy odor on site.
3. Thawed sludge layer on D, E can be pulled off in 4" x 4" sheets with a spatula. Thawed sludge layer on G, H is still lacking shear strength except where advanced drying has been effected by direct radiant energy from the sun.

FIELD THAW DATA - 18

DATE May 2, 1971 TIME: 5:00 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	6-11/16	-	3/8	Some damp spots showing through mold.
B	4-9/16	-	3/16	Same as A.
C	19-3/16	3/16	1/4	Some damp spots. Very little liquid, even at walls.
D	4-3/4	3/16	1/16	Solid black ice below thawed layer. Thawed layer wetter than yesterday.
E	5-13/16	3/16	1/8	Same as D.
F	20-7/16	1/8	5/8	Clear ice has melted through to sludge. Solids at center line. Solid black ice below thawed layer. No sampleable liquid.
G	3-1/16	5/8	3/4	About 75% exposed sludge solids. Solid black ice below thawed layer.
H	2-11/16	1/2	3/8	85% exposed sludge solids. Remainder is clear ice over solids in SE corner. NW quadrant thawed to sand-1-1/8" depth of sludge.
J	14-7/8	1/16	1/2	No sampleable liquid. Remaining clear ice appears to be zero to 6" in depth above concentrated solids.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. C, F and J are now tipped toward the south and their foundations are stable. Effects of direct radiant energy of the sun are very noticeable in box F.
2. Local snow runoff water is increasing in depth but not affecting thaw in beds.
3. No obnoxious odors on site.
4. The beds experienced more advance in thaw today than any previous day.
5. Large amount of thaw renders the thawed sludge layer wetter due to a rapid increase in the amount of released water before evaporation can handle it.
6. Clear ice remaining on G and H is in shaded SE corner of beds.
7. When F tilted, the floor of the box separated slightly from the walls to expose sand. The sand was examined and found to be very dry.

FIELD THAW DATA - 19

DATE MAY 3, 1971 TIME: 4:30 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	5-15/16	1/16	3/4	Starting to thaw under mold. No sampleable liquid.
B	3-15/16	1/16	5/8	Same as A. Both have mold thickness 1/2".
C	18-3/8	1/16	13/16	Film of thawed sludge. Damp spots through mold are increasing.
D	4-3/8	3/8	3/8	Solid ice below thawed sludge layer. Not much change.
E	5-9/16	3/8	1/4	Same as D. No sampleable liquid.
F	18-1/2	3/8	1-15/16	30% exposed sludge solids where sunshines. Musty odor No sampleable liquid.
G	2-7/16	3/4	5/8	85% exposed sludge solids. Solid black ice below thawed layer. Ice shrinking 2" from walls.
H	2-5/16	3/4	3/8	90% exposed sludge solids. NW quadrant thawed to sand. Depth of solids here = 1-1/2".
J	14-3/8	1/16	1/2	Quite dry. No odor in box. No sampleable liquid.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odors on site.
2. Exterior walls of all the beds have remained dry throughout the thaw.
3. Perforated pipes have never shown evidence of liquid drainage but are now protruding into snow runoff water due to tilt.
4. Note acceleration in thaw of C, F due to effect of receiving direct solar energy. J had always received more direct solar energy but its sludge level is now in the shadows. The heat source for J would largely be from conduction and convection.
5. J is showing some solids at this level - these are due to disturbance of concentrated solids at bottom during core sampling. This bed froze in layers and portions experienced more than one freeze-thaw cycle.

FIELD THAW DATA - 20

DATE May 4, 1971 TIME: 5:00 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	5-7/8	1/16	1/16	Dry on surface, some thaw under mold.
B	3-3/4	1/16	3/16	Same as A.
C	18	1/16	3/8	Not much change.
D	4-1/4	1/2	1/8	Not much change.
E	5-3/8	1/2	3/16	Not much change.
F	18	1/2	1/2	35% exposed sludge solids. Solid black ice below thawed layer.
G	2-1/8	3/4	5/16	90% exposed sludge solids. Solid ice beneath thawed layer.
H	2-1/16	3/4	1/4	95% exposed sludge solids. NW corner thawed to sand.
J	14-3/16	1/16	3/16	30-40% exposed sludge layer. No odor in box.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No sampleable liquid in any of the beds.
2. No odor on site.

FIELD THAW DATA - 21

DATE May 5, 1971 TIME: 4:00 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	5-3/8	1/16	1/2	Not much change.
B	3-3/8	1/16	3/8	Some ice shrinkage away from the wall.
C	17-3/4	3/4	1/4	Some ice shrinkage from walls. Dampish through mold.
D	3-13/16	1/2	7/16	Not much change.
E	5-1/4	1/2	1/8	Same as D.
F	17-1/2	3/8	1/2	60% exposed sludge solids. Black solid ice below thawed layer.
G	1-15/16	5/8	3/16	95% exposed sludge solids. Still solid ice below thawed layer. Thawed to sand in NW corner 2" depth.
H	1-13/16	5/8	1/4	99% exposed sludge solids. Thawed to sand in NW corner.
J	13-11/16	1/16	1/2	70% exposed sludge layer.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odor on site.

2. No sampleable liquid in any of the beds.

FIELD THAW DATA - 22

DATE May 6, 1971 TIME: 3:40 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	4-3/8	-	1	Not much change. Solid ice under mold quite dry.
B	2-15/16	-	7/16	Same as A.
C	17-1/16	3/4	11/16	Solid ice beneath thawed layer. Thawed layer wet.
D	3-11/16	1/2	1/8	Surface is damp to the touch. Not much change.
E	4-7/8	1/2	3/8	Not much change. Thawed layer quite dry.
F	16-11/16	9/16	13/16	90% exposed sludge solids. Solid ice below thawed layer.
G	1-3/16	9/16	3/4	100% exposed sludge solids. Still solid ice below except wall shrinkage 1-1/2-2".
H	1-5/16	3/8	1/2	100% exposed sludge solids. 40% thawed right to sand depth = 1-1/2". Not near as much wall shrinkage as G.
J	13	1/16	11/16	70% exposed sludge layer.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odor on site.
2. Started recording relative humidity today.
3. Box A has tilted slightly west due to quicking condition of gravel underlay. Local snowmelt runoff not directly affecting thaw. Note acceleration in thaw due to increased direct solar energy.
4. Thawed sludge in D and E now forkable.
5. No sampleable liquid in any of the beds. Thawed layer in F is quite wet but water seems to be tightly bound. There is no place for this water to go but to evaporation. It is restricted in its movement on its other boundaries.
6. Styrofoam insulation on B, E, H appears to retard wall shrinkage thus cutting off one heat transfer path.

FIELD THAW DATA - 23

DATE May 7, , 1971 TIME: 5:45 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	4-1/8	1/2	1/4	Thawed sludge layer quite dry.
B	2-1/2	1/2	7/16	Same as A.
C	16-9/16	3/4	1/2	Thawed sludge wetter than A,B.
D	3-7/16	1/2	1/4	Thawed sludge layer is scarcely damp to touch.
E	4-5/8	1/2	1/4	Same as D.
F	16-1/4	9/16	7/16	100% exposed sludge solids. Thawed sludge layer wetter than D,E.
G	-	1	-	100% exposed sludge solids. NW quadrant thawed to sand. Depth of sludge here = 1-1/4". Still some solid ice below thawed layer in rest of bed.
H	1-1/6	3/4	1/4	100% exposed sludge solids. Most of N half of bed thawed to sand. S half still underlain by solid ice.
J	12-9/16	1/16	7/16	70% exposed sludge layer underlain by new layer of clear ice. Evidence of layered freezing.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. Light snow, cool and breezy.
2. No sampleable liquid in any of the beds.
3. No odors on site.
4. Local snowmelt runoff has been stabilized and is being drawn down by College Utilities portable pump.
5. D and E may have received additional freeze-thaw cycle last night. (See temperature data). A and B thawed sludge is very dense with the water tightly bound.

FIELD THAW DATA - 24

DATE May 8, 1971 TIME: 6:30 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	3-3/4	1/2	3/8	More exposed sludge extending through mold. Quite dry.
B	2-5/16	1/2	3/16	Same as A.
C	16-9/16	3/4	0	Dry, not much change.
D	3-1/4	5/8	3/16	Thawed sludge forkable.
E	4-5/8	5/8	0	Same as D.
F	16-1/3	9/16	1/8	Much thicker thawed sludge layer where exposed to direct rays of sun. Getting dryer.
G	-	5/8	-	Sludge is shrinking laterally. SE corner still underlain by ice.
H	1	1-1/4	1/16	N half thawed to sand, depth 1-1/4". Portions of S half thawed to sand.
J	12-7/16	1/16	1/8	Solid, clear ice under initial thawed sludge layer.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No sampleable liquid in any of the beds.
2. No odors on site.
3. As the thawed sludge layer in G and H is starting to dewater and lose some some of its depth. Thawed sludge layer acts as an insulator in the beds.

FIELD THAW DATA - 25

DATE May 9, 1971 TIME: 5:45 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	3-5/8	1/2	1/8	Some wall shrinkage. Underlying ice is getting rotten, can stab through it with spatula.
B	2-1/4	1/2	1/6	Same as A.
C	16-1/4	1/2	5/16	Not much change.
D	3-1/4	1/2	0	Ice beneath thawed sludge layer is very rotten. Can stab to sand with spatula.
E	4-5/16	1/2	5/16	Similar to D. Thawed layer acts as insulator.
F	15-15/16 n	5/8	3/16	Ice much more solid than D,E.
G	-	1-1/2	-	50% thawed to sand. Thawed portion ready for final disposal.
H	-	1-1/4	-	60% complete thaw. Not as much wall shrinkage as G. Forkable-ready for final disposal where thawed.
J	11-15/16	-	1/2	Mostly clear ice, solids have drained off. Major portion of concentrated sludge still not exposed.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. Local runoff water is progressively lowering - no effects on thaw except earlier tilting of boxes.
2. No obnoxious odors on site.
3. No sampleable liquid in any of the beds.

FIELD THAW DATA - 26

DATE May 10, 1971 TIME: 3:20 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	3-1/2	1/2	1-1/8	Progressively larger areas of thawed sludge being exposed through mold. Ice rotten beneath thawed layer.
B	2	1/2	1/4	Dry. Ice under thawed layer is more solid than in A.
C	16	3/4	1/4	Ice beneath thawed layer very solid. Thawed sludge quite wet.
D	3-1/4	1/2	0	Very dry thawed sludge - easily forked into 6" x 6" mat. Rotten ice below thawed layer.
E	4-1/16	1/2	1/4	Similar to D except underlying ice more solid than D.
F	15-11/16	9/16	1/4	Dry. Ice quite solid beneath thawed sludge layer.
G	2	1-1/2	-	Wall shrinkage about 1" around periphery. 20% of bed still underlain with semi solid ice.
H	-	1-1/4	-	Not as much wall shrinkage as G. Easily forked into 1' x 1' sheets. 20% still underlain by ice.
J	11-1/2	-	7/16	Clear ice very solid. Ice has film of water.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odors on site.
2. No sampleable liquid in any of the beds.
3. Styrofoam insulation helps maintain solid ice below thawed sludge layer in B,E.
4. Where sludge layer has completely thawed to sand in G,H, the entire depth is very dry and ready for utlimate disposal.
5. Perforated pipes: C - 3/4 submerged in snowmelt water.
   F - Fully submerged.
   J - Not submerged.

FIELD THAW DATA - 27

DATE May 11, , 1971 TIME: 3:00 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	2-15/16	1/2	9/16	Ice beneath thawed layer is very rotten. Considerable wall shrinkage.
B	1-3/4	5/8	1/4	Ice more solid than that in A.
C	15-5/16	3/4	11/16	Dry. Ice much more solid than A,B.
D	2-13/16	3/4	7/6	Ice very rotten under thawed layer. Thawed layer very dry.
E	3-9/16	3/4	1/2	Ice more solid than that in D. Thawed sludge layer forkable.
F	15-1/16	5/8	5/8	Ice more solid than D,E. Dry.
G	-	1-1/2	-	Very dry throughout. 100% thawed to sand.
H	-	1-1/4	-	80% thawed to sand. Very dry throughout. Some ice in SE corner.
J	10-7/8	-	5/8	Clear ice has a 1" diameter hole in north half. Can see distinct separation of concentration. Solids and clear ice.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odor on site.
2. Thaw in A,B,D,E, is progressing from walls inward; periphery experiences complete thaw while interior of box still underlain by fairly solid ice.
3. Moisture content of thawed layer in A,B,D,E increases with depth-maximum at sand-sludge interface.
4. If thawed surfaces on the beds were never disturbed, the time for complete thaw would have been greatly increased. Representative vertical and horizontal sampling breaks the continuous natural insulation which is produced by the drying thawed layer. Once this surface is disturbed the heat transfer has a path through which to penetrate the bed.
5. No sampleable liquid in any of the beds.
6. Perforated pipes no longer submerged in snow meltwater.

FIELD THAW DATA - 28

DATE May 12, , 1971 TIME: 5:30 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	2-1/4	3/4	9/16	Peripheral thaw complete to sand, about 4" width. Wall shrinkage averages 2". Some odor.
B	1-11/16	3/4	1/16	Box interior still underlain with rotten ice, some peripheral thaw to sand.
C	14-7/16	1	7/8	Thawed sludge layer still quite wet. Underlying ice still solid.
D	2-1/4	3/4	9/16	Interior still underlain with rotten ice. Thawed layer very dry, forkable.
E	2-13/16	3/4	3/[illegible]	Not as much wall shrinkage as D. Thawed sludge very dry.
F	14-1/4	3/4	13/16	Ice very solid under thawed layer. No odor.
G	-	1-3/8	-	100% thawed to sand. Lateral and vertical shrinkage underlying sand is quite dry.
H	-	1	-	Wall shrinkage about 1/2". Forming drying cracks on surface. 95% completely thawed to sand.
J	9-9/16	-	1-5/16	Clear ice is a shell above concentrated sludge at bottom. The sludge is 3" below bottom of clear ice shell. Sludge highly odorous - digestion likely setting in.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odors on site.
2. No evidence of flow from perforated pipe.
3. No sampleable liquid in any of the beds.
4. Beds have endured very well structurally.
5. Thawed sludge depth above, refers to thawed layer above ice in the beds still underlain with ice and recording Total Frozen Sludge Depth.
6. Sludge in J appears to have never experienced complete freezing. It has a different consistency than the sludge which was completely frozen.

FIELD THAW DATA - 29

DATE May 13, , 1971 TIME: 5:20 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	2-3/8	-	4-6" peripheral thaw to sand. Rotten ice in interior. Moisture at depth is lessening.
B	-	2-3/8	-	1-3" peripheral thaw to sand interior, ice more solid than A.
C	13-1/2	1	15/16	Thawed sludge layer is wet but water is bound. Solid ice under thawed layer.
D	-	2-5/16	-	6" peripheral thaw. Some fairly solid ice in bed interior. Sludge easily caked.
E	-	2-7/8	-	Ice more solid than that in D. Can easily get 6" diam. x 3" cake.
F	13-7/16	3/4	13/16	Very solid ice below thawed layer. Some odor in bed.
G	-	1-1/2	-	Stable sludge shrinkage cracks. Sludge in interior as thin as 3/4". Very dry.
H	-	1-1/2	-	SE corner raises avg. thawed depth. Stable sludge. Very little ice. Sludge in interior as thin as 1/2".
J	8-13/16	2	1-3/4	Considerable anaerobic odor. Clear ice shell is shrinking. "Total frozen sludge depth" is to shell. Very rotten ice below thawed layer. No free liquid.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No evidence of flow from perforated pipes.
2. A,B,D,E now recording average thawed sludge depth - measured at periphery where thaw is complete to sand.
3. Uninsulated beds show quicker peripheral thaw than insulated ones.

FIELD THAW DATA - 30

DATE May 14, 1971 TIME: 3:30 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	2-1/4	-	50% completely thawed to sand. Dry. No odor.
B	-	2-1/4	-	Ice still quite solid in interior. 30% completely thawed to sand, dry.
C	12-15/16	2-1/2	9/16	Dry at surface. Ice still solid.
D	-	2-1/8	-	40-50% completely thawed to sand. Rotten ice in interior. Sand shrinkage cracks.
E	-	2-7/8	-	Shrinkage cracks. Interior ice more solid than D.
F	13-1/8	3/4	5/16	Some odor, musty. Dry, not much wall shrinkage.
G	-	1-1/2	-	Sludge is compressible cake. 1-3/4" wall shrinkage.
H	-	1-1/2	-	Very dry. 3/4" wall shrinkage. Even dry at depth.
J	8	2-1/2	13/16	50% of clear ice shell is melted. No sampleable liquid. Rotten ice under thawed layer. Odor.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. Slight anaerobic odor on site emanating from J.
2. Shaded site under canopy is considerably cooler than outside canopy. Thaw / Would be much faster than if no canopy.

FIELD THAW DATA - 31

DATE May 15, 1971 TIME: 5:00 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	1-3/4	-	Very dry at surface, some moisture at depth. 70% completely thawed to sand. Remaining ice is black, rotten.
B	-	1-7/8	-	50% completely thawed to sand. Otherwise same as A.
C	12-3/16	1-1/4	3/4	Musty odor. Ice still solid.
D	-	1-7/8	-	Very dry, not much moisture at depth. Shrinkage cracks. 45% completely thawed to sand.
E	-	2-1/8	-	Some moisture at depth. Thawed sludge is compressible. 20% completely thawed to sand.
F	12-5/8	1-1/4	1/2	Ice starting to rot. Some odor.
G	-	1-1/2	-	Fairly stable conditions. More shrinkage cracks. Sludge depth at centre = 3/4".
H	-	1-1/2	-	Sludge depth at centre = 5/8". Stable conditions. Sludge very dry and light in weight.
J	6-1/2**	3	1-1/2	Odorous. Ice shell now only 20% of surface. Remaining sludge quite dry. Complete thaw to sand at centre line 3" depth. Looks like this bed froze only at periphery and centreline.

*These depths are averaged over the area of the bed.
**To clear ice shell.
Depths are all shown in inches

GENERAL REMARKS:

1. No evidence of flow from perforated pipes.
2. Beds are now drying, as well as thawing, as evidenced by continuous loss in depth of thawed layer. Lateral shrinkage also is an effect of drying. Also note total solids determinations.
3. No sampleable liquid in any of the beds.
4. The beds except for C and F could easily be cleared of sludge by breaking the rotten ice and carrying it away to final disposal in pieces.
5. Bed E is slowest of small beds to thaw since it receives no direct sunlight and is well insulated.

FIELD THAW DATA - 32

DATE May 16, 1971 TIME: 4:30 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	1-3/4	-	85% completely thawed to sand. Very rotten ice. Sludge compressible where thawed.
B	-	1-3/4	-	50% completely thawed to sand. Ice more solid than A.
C	11-3/4	1-1/4	7/16	Musty odor. Ice still solid.
D	-	1-3/4	-	Shrinkage cracks. Some wall shrinkage. 75% completely thawed to sand.
E	-	1-7/8	-	15% completely thawed to sand. Solid ice in interior. Dry even at depth.
F	12-3/16	1-1/3	7/16	Ice still solid. Some odor. Marked influence of South sun.
G	-	1-1/2	-	Stable. Very dry. Tightly coagulated solids.
H	-	1-5/16	-	Stable. 100% complete thaw. Wall shrinkage = 1".
J	5-3/16	2-1/2	1-5/16	15% of clear ice shell remaining. Substantial odor. Quite dry. Depth to sand at centre line 3-1/4". Some ice in interior at 2-1/2" depth. Mode of freezing confirmed as described May 15.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. Very little site odor.
2. No sampleable liquid in any of the boxes.
3. No evidence of flow from perforated pipes.
4. Vertical shrinkage of thawed sludge layer decelerates quickly with time. The depth appears to level off at a compressible thickness.

FIELD THAW DATA - 33

DATE May 18, 1971 TIME: 4:20 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	1-3/4	-	100% thawed to sand. Quite dry at depth. Wall shrinkage starting.
B	-	1-3/4	-	90% completely thawed to sand. Frozen portion well insulated all sides.
C	9	1-1/2	2-3/4	Solid ice under sludge.
D	-	1-3/4	-	75% completely thawed to sand. Still solid ice in interior. Shrinkage cracks.
E	-	1-7/8	-	20% completely thawed to sand. Shrinkage cracks at surface. Very dry.
F	9-13/16	1-1/2	2-3/8	Still solid ice below thawed layer. Wall shrinkage starting. Very dry at surface.
G	-	1-3/8	-	Very dry, including sand. Wall shrinkage = 2". Sludge starting to curl away from sand.
H	-	7/8	-	Very dry, including sand. Shrinkage cracks. Wall shrinkage = 1".
J	1/8	3	5-1/6	Clear ice completely melted. Still has some odor. NE quadrant still has some ice. All of S half is thawed to sand.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odors on site.
2. No evidence of flow from perforated pipe.
3. No sampleable liquid in any of the beds.

FIELD THAW DATA - 34

DATE May 20, 1971 TIME: 3:30 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	1-3/4	-	Lateral shrinkage is slow. Not much change.
B	-	1-3/4	-	100% completely thawed to sand. Very little lateral shrinkage.
C	7-1/2	1-3/4	1-1/2	Ice is starting to rot in places. Very little wall shrinkage. Dry.
D	-	1-3/4	-	90% completely thawed to sand. Remaining ice in interior.
E	-	1-3/4	-	50% completely thawed to sand. Ice still solid in interior. Very dry.
F	9-11/16	2	1-1/8	Very dry at surface. Very little wall shrinkage. Ice starting to melt.
G	-	1-1/8	-	Not much change.
H	-	7/8	-	Not much change.
J	-	3	-	Odor lessening. 95% completely thawed to sand.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. As J continues to dry, the site odor decreases.
2. No evidence of flow from perforated pipes, no sampleable liquid in any of the beds.
3. Very obvious that small beds thaw mainly from walls inward.

FIELD THAW DATA - 35

DATE May 22, 1971 TIME: 3:10 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	1-3/4	-	Very dry. Ready for final disposal.
B	-	1-3/4	-	Same as A.
C	5-15/16	2	1-9/16	Thaw progressing.
D	-	1-3/4	-	100% completely thawed to sand. Dry even at depth. 1" wall shrinkage.
E	-	1-3/4	-	75% completely thawed to sand.
F	8	2-5/8	1-11/16	Ice rotting in S half. Surface very dry.
G	-	1	-	2" wall shrink. Remaining sludge tightly coagulated. Considerable shear strength.
H	-	7/8	-	1-1/2" wall shrink. Sludge can be lifted as unit.
J	-	3	-	Some odor. 100% thawed to sand.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odors on site.
2. Thaw in deep beds C and F progresses much more rapidly after wall shrinkage allows more direct heat transfer.

FIELD THAW DATA - 36

DATE May 24, 1971 TIME: 4:10 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	1-5/8	-	Very dry throughout. Little wall shrink.
B	-	1-3/4	-	Very dry throughout. Little wall shrink.
C	4-3/16	2-5/8	1-13/16	Ice starting to rot where sun shines. Dry at surface.
D	-	1-1/2	-	Sludge starting to curl from sand. Very dry.
E	-	1-5/8	-	100% complete thaw to sand. Starting to curl from sand.
F	6-13/16	3-1/4	1-3/16	Ice rotting in S half. Some shrinkage at N wall.
G	-	1	-	3" wall shrinkage. Sludge getting very hard.
H	-	7/8	-	2" wall shrinkage. Very dry.
J	-	3	-	Some drying cracks. No odor.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odor on site.
2. Some flies in area but no nuisance organisms in beds.
3. Advanced drying in G,H produces very hard surface on sludge, like dried clay. Tightly coagulated solids, it is easy to lift a 1' x 1' mat.

FIELD THAW DATA - 37

DATE May 26, 1971 TIME: 2:00 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	1-3/4	-	Very dry. Wall shrink 1".
B	-	1-5/8	-	Very dry. Wall shrink 1/2".
C	2-11/16	3-1/2	1-1/2	Very little wall shrink. Ice rotting. Very dry.
D	-	1-1/2	-	Very dry. Wall shrink 2".
E	-	1-5/8	-	Very dry. Wall shrink 1-1/2".
F	4-7/16	2-1/2	2-3/8	Rotting ice, solid in shade.
G	-	7/8	-	Wall shrink 4".
H	-	7/8	-	Wall shrink 2-1/2".
J	-	3	-	Shrinkage cracks. Very dry in all quadrants except SE, some moisture at depth.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. Photographs of beds taken today.
2. No odor on site.

FIELD THAW DATA - 38

DATE May 28, 1971 TIME: 3:10 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	1-3/4	-	Appears to be stable.
B	-	1-5/8	-	Appears to be stable.
C	1/4	6-1/4	2-1/8	Moisture at depth. 40% completely thawed to sand. Very forkable. Easy 8" x 8" x 4" piece.
D	-	1-1/2	-	Appears to be stable.
E	-	1-5/8	-	Appears to be stable.
F	1-5/16	5-1/2	3-1/8	S half completely thawed to sand. Good sludge cake, soil-like. Remaining ice very rotten.
G	-	7/8	-	Appears to be stable.
H	-	7/8	-	Appears to be stable.
J	-	3	-	Negligible odor. Drying at depth.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. Musty odor on site.
2. A sporadic drip from perforated pipe in C. Perforated pipes in F and J are dry.
3. A very large amount of thaw in C and F since last measurements. Thawed sludge depths shown for these beds are averaged from the thawed periphery of each bed.

FIELD THAW DATA - 39

DATE May 30, 1971 TIME: 1:30 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	1-3/4	-	Stable.
B	-	1-5/8	-	Stable.
C	-	6-1/4	1/4	Some moisture at depth. 100% completely thawed to sand.
D	-	1-1/2	-	Stable.
E	-	1-5/8	-	Stable.
F	5/16	6-7/8	1	75% thawed completely to sand. Sand dry and clean under thawed sludge layer.
G	-	7/8	-	Stable.
H	-	7/8	-	Stable.
J	-	3	-	Very little odor. Sludge very dry, sand is dry.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. Average thawed sludge depth in Bed F is for portion of bed which is completely thawed to sand.

FIELD THAW DATA - 40

DATE June 2, 1971 TIME: 11:45 AM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	1-3/4	-	Not much change, sludge curling from sand.
B	-	1-5/8	-	Same as A.
C	-	5-1/8	-	Very dry, sludge is curling from sand. Sludge has hard surface upon drying.
D	-	1-1/2	-	Not much change, sludge curling from sand.
E	-	1-1/2	-	Same as D.
F	-	5-1/4	1	Very dry at surface, 100% thawed. Sand dry and clean. No odor.
G	-	3/4	-	Not much change.
H	-	3/4	-	Not much change.
J	-	3	-	No odor. Very dry.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No evidence of flow in any of the perforated pipes.
2. No odor on site.

FIELD THAW DATA - 41

DATE June 5, 1971 TIME: 11:00 AM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	1-3/4	-	Stable.
B	-	1-5/8	-	Stable.
C	-	4-1/8	-	Very dry, hard at surface. Some moisture at depth.
D	-	1-1/2	-	Stable.
E	-	1-1/2	-	Stable.
F	-	3-3/4	-	Very dry, hard at surface. Some moisture at depth.
G	-	3/4	-	Stable.
H	-	3/4	-	Stable.
J	-	2-1/4	-	Very dry at surface. Very little moisture at depth.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. Beds are undergoing advanced drying - hardening at surface.
2. No odor on site.
3. Beds are not of completely uniform thickness, J is much thicker in NE and NW corners than in interior. This could be due partly to heaving upon freezing.

FIELD THAW DATA - 42

DATE June 9, 1971 TIME: 3:30 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	1-3/4	-	Stable.
B	-	1-5/8	-	Stable.
C	-	4	-	Dry, hard crust at surface. Some moisture at depth.
D	-	1-1/2	-	-
E	-	1-1/2	-	Stable.
F	-	3-1/2	-	Dry, hard crust at surface. Some moisture at depth.
G	-	3/4	-	Stable.
H	-	3/4	-	Stable.
J	-	2	-	Very dry throughout.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. Sunny, calm and 82°F.
2. No odors on site.
3. Advanced drying includes curling of the tightly coagulated sludge solids from the sand and slow shrinkage from the bed walls.

FIELD THAW DATA - 43

DATE June 17, 1971 TIME: 2:45 PM

BED	TOTAL FROZEN SLUDGE DEPTH (AVG.)*	THAWED SLUDGE DEPTH (AVG.)*	AVG. LOSS IN TOTAL DEPTH	REMARKS
A	-	Not recorded	-	White fungi growing between dry and moist layers.
B	-	"	-	Not much change.
C	-	"	-	Not much change.
D	-	"	-	Not much change.
E	-	"	-	Not much change.
F	-	"	-	Not much change.
G	-	"	-	Not much change.
H	-	"	-	Not much change.
J	-	"	-	Not much change.

*These depths are averaged over the area of the bed.

Depths are all shown in inches

GENERAL REMARKS:

1. No odor on site.
2. Photographs taken today.

APPENDIX IV - EVAPORATION CALCULATIONS

APPENDIX IV EVAPORATION CALCULATIONS

PG 11-4 CHOW. HANDBOOK OF APPLIED HYDROLOGY

Use Meyer Equation:

$$E = C\,(e_w - e_a)\,\psi \qquad \psi = 1 + 0.1\,w$$

E = rate of evaporation (inches per 30 day month)

C = Coefficient depending on various uncounted factors affecting evaporation $C = 15$ small, shallow water in Meyer Equation.

e_w = Maximum vapor pressure (inches Hg) corresponding to monthly mean air temperature observed at nearby stations for small bodies of shallow water.

e_a = Actual vapor pressure in air based on monthly mean air temperature and relative humidity at nearby stations for small bodies of shallow water.

ψ = Wind factor

w = Monthly mean wind velocity, in mph, at about 30ft. above ground.

For Sludge Beds:

$$C = 15$$

Mean Monthly air temperature = 47.3°F**

Mean Monthly relative humidity = 33%*

w = 9.1 mph**

$\psi = 1 + 0.1\,(9.1) = 1.91$

Now $E = 15 \times 1.91\,(e_w - e_a) = 28.6\,(e_w - e_a)$

Saturation vapor pressure - e'_w

At pressure p and temperature T
(pg 347, Smithsonian Meteorological Tables prepared by Robert J. List, 1966).

Vapor pressure e' at total pressure p and with mixing ratio r.

pg 351 Tables:

$$e'_w = e_w \text{ (Chow)}$$

*Averaged from my data May 6 - June 2, 1971.
**From National Weather Service, Fairbanks International Airport.

$$47.3°F = 5/9\ (47.3-32)$$

$$= \frac{5}{9}\ (15.3) = \frac{76.5}{9} = 8.5°C$$

e'_w @ 8.5°C = 11.092 mb

1 bar = 760 mm. Hg. (Standard atmospheric pressure)
1 mb = 0.76 mm.

$$e_w = 11.092 \times 0.769 \text{ mm Hg}$$

1" = 2.54 cm

= 25.4 mm

$$e_w = \frac{11.092 \text{ X } 0.760}{25.4} \text{ inches Hg}$$

$e_a = 0.33\ e_w$ [See pg 3-4 CHOW]

$e_w - e_a = 0.67\ e_w$

$$E = 0.67 \text{ X } 28.6 \text{ X } 11.092 \text{ X } \frac{0.760}{25.4} \text{ inches/30 days}$$

E = <u>6.36"</u> = rate of evaporation in 30 day period

Losses in bed depths during May:

A = 5-5/16"
B = 3-1/8"
C = 13-3/16"
D = 3-1/2"
E = 4-5/8"
F = 14-3/16"
G = 3-9/16"
H = 3-1/16"
J = 12-3/8"

APPENDIX V - SLUDGE VOLUME CHARACTERISTICS

APPENDIX V. SLUDGE VOLUME CALCULATIONS

Echenfelder, W. Wesley Jr.

Water Quality Engineering for Practicing Engineers

Barnes and Noble, Inc. New York (1970) p. 196 Extended Aeration.

The excess sludge will be the nonbiodegradable residue and will be approximately equal to

AX_V = 0.23 a Sr - effluent loss

Sr = lb/day of BOD removed

a_o = fraction of BOD converted to degradable sludge

= 0.88a

$a = \frac{a_o}{0.88}$

"In a continuous completely mixed extended aeration plant with intermittent sludge wasting from the final clarifier, both biodegradable and non-biodegradable sludge will be wasted from the mixture. Total wastage about double that calculated in equation above."

a = 0.37 - 0.46 for readily degradable organic wastes

= yield coefficient

a = 0.73 for domestic waste

March 1971 Data. K. R. Ranganathan

Flow ∿ 300,000 gal/day

Influent S.S. ∿ 1.75 mg/l

V.S.S. ∿ 70%

BOD ∿ 240 mg/l

Effluent Removal of BOD = 82.8%

S.S. ∿ 15 mg/l

V.S.S. ∿ 70%

Volume of Sludge to be wasted = ΔX_v = 0.23 a Sr-effluent loss

a = 0.73

Sr = BOD (lb/day) removed

BOD removed = 0.828 X 240 = 199 mg/l

$$\text{lb BOD removed} = 199 \times \frac{300000}{10^6} \times 8.33 \ \frac{\text{lb}}{\text{gal}}$$

$$= 0.3 \times 199 \times 8.33$$

$$= 497 \text{ lb/day}$$

Non biodegradable effluent loss =

$$0.30 \times 15 \text{ mg/l} \times \frac{300000}{10^6} \times 8.33 \ \frac{\text{lb}}{\text{gal}}$$

$$= 4.5 \times 0.3 \times 8.33$$

$$= 1.35 \times 8.33 = 11.2 \text{ \#/day}$$

$$\text{Excess Sludge Solids} = \Delta X_v = (0.23 \times 0.73 \times 497) - 11.2$$

$$= 83.5 - 11.2$$

$$= 72.3 \text{ \#/day}$$

Wasted solids = 2 X 72.3 = 144.6 say 145 lbs

Assume solids conc. of wasted sludge = 1.5%

$$\text{Wt. of slurry} = \frac{145}{0.015} = 9670 \text{ lb}$$

Assume S.G. = 1.0

Volume = 9670/62.4 = 155 ft^3